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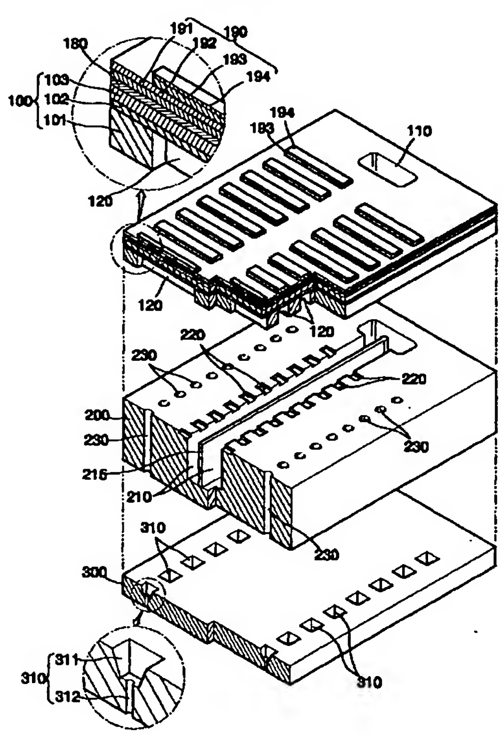
(54) Piezoelectric ink-jet printhead and method for manufacturing the same

(57) A piezoelectric ink-jet printhead and a method for manufacturing the same are provided. The piezoelectric ink-jet printhead is formed by stacking three monocrystalline silicon substrates (100, 200, 300) on one another and adhering them to one another. The three substrates include an upper substrate (100), in which an ink supply hole (110) and on a bottom surface of which a pressure chamber (120) are formed, an intermediate substrate (200), in which an ink reservoir (210) and a damper (230) are formed, and a lower substrate (300) in which a nozzle (310) is formed. A restrictor (220), which connects the ink reservoir to the pressure chamber, may be formed on the upper substrate or intermediate substrate. A piezoelectric actuator is monolithically formed on the upper substrate.

FIG. 5



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Description

[0001] The present invention relates to an ink-jet printhead, and more particularly, to a piezoelectric ink-jet printhead made on a silicon substrate, and a method for manufacturing the same using a micromachining technology.

[0002] In general, ink-jet printheads are devices for printing in a predetermined color image by ejecting a small volume of droplet of printing ink at a desired position on a recording sheet. Ink ejection mechanisms of an ink-jet printer are largely categorized into two different types: an electro-thermal transducer type (bubble-jet type) in which a heat source is employed to form bubbles in ink, thereby causing the ink to be ejected, and an electro-mechanical transducer type in which ink is ejected by a change in ink volume due to deformation of a piezoelectric element.

[0003] The typical structure of an ink-jet printhead using an electro-mechanical transducer is shown in FIG. 1. Referring to FIG. 1, an ink reservoir 2, a restrictor 3, an ink chamber 4, and a nozzle 5 for forming an ink passage are formed in a passage forming plate 1, and a piezoelectric actuator 6 is provided on the passage forming plate 1. The ink reservoir 2 stores ink supplied from an ink container (not shown), and the restrictor 3 is a passage through which ink is supplied to the ink chamber 4 from the ink reservoir 2. The ink chamber 4 is filled with ink to be ejected. The volume of the ink chamber 4 is varied by driving the piezoelectric actuator 6, thereby a variation in pressure for ink ejection or inflow is generated. The ink chamber 4 is also referred to as a pressure chamber.

[0004] The passage forming plate 1 is formed by cutting a plurality of thin plates formed of ceramics, metals, or plastics, forming a part of the ink passage, and then stacking the plurality of thin plates. The piezoelectric actuator 6 is provided above the ink chamber 4 and includes a piezoelectric thin plate stacked on an electrode for applying a voltage to the piezoelectric thin plate. As such, a portion forming an upper wall of the ink chamber 4 of the passage forming plate 1 serves as a vibration plate 1a to be deformed by the piezoelectric actuator 6.

[0005] The operation of a conventional piezoelectric ink-jet printhead having the above structure will be described below.

[0006] If the vibration plate 1a is deformed by driving the piezoelectric actuator 6, the volume of the ink chamber 4 is reduced. As a result, due to a variation in pressure in the ink chamber 4, ink in the ink chamber 4 is ejected through the nozzle 5. Subsequently, if the vibration plate 1a is restored to an original state by driving the piezoelectric actuator 6, the volume of the ink chamber 4 is increased. As a result, due to a variation in a pressure in the ink chamber 4, ink stored in the ink reservoir 2 is supplied to the ink chamber 4 through the restrictor 3.

[0007] As an example of the piezoelectric ink-jet printhead, a conventional piezoelectric ink-jet printhead disclosed in U.S. Patent No. 5,856,837 is shown in FIG. 2. FIG. 3 is a cross-sectional view of the conventional piezoelectric ink-jet printhead in a lengthwise direction of a pressure chamber of FIG. 2, and FIG. 4 is a cross-sectional view taken along line A-A' of FIG. 3.

[0008] Regarding to FIGS. 2 through 4, the conventional piezoelectric ink-jet printhead is formed by stacking a plurality of thin plates 11 to 16 and adhering to one another. That is, a first plate 11, on which a nozzle 11a through which ink is ejected, is formed and then is placed on the bottom of the printhead, a second plate 12, on which an ink reservoir 12a and an ink outlet 12b are formed, is stacked on the first plate 11, and a third plate 13, on which an ink inlet 13a and an ink outlet 13b are formed, is stacked on the second plate 12. An ink supply hole 17, through which ink is supplied to the ink reservoir 12a from an ink container (not shown), is provided on the third plate 13. A fourth plate 6, on which an ink inlet 14a and an ink outlet 14b are formed, is stacked on the third plate 13, and a fifth plate 15, on which a pressure chamber 15a, both ends of which communicate with the ink inlet 14a and the ink outlet 14b, respectively, is formed, is stacked on the fourth plate 6. The ink inlets 13a and 14a serve as a passage through which ink is supplied to the pressure chamber 15a from the ink reservoir 12a, and the ink outlets 12b, 13b, and 14b serves as a passage through which ink is ejected to the nozzle 11a from the pressure chamber 15a. A sixth plate 16 for closing the upper portion of the pressure chamber 15a is stacked on the fifth plate 15, and a driving electrode 20 and a piezoelectric layer 21 are formed as a piezoelectric actuator on the sixth plate 16. Thus, the sixth plate 16 serves as a vibration plate operated by the piezoelectric actuator, and the volume of the pressure chamber 15a under the sixth plate 16 is varied according to the deformation of the vibration plate.

[0009] In general, the first, second, and third plates 11, 12, and 13 are formed by etching or press-working a metal thin plate, and the fourth, fifth, and sixth plates 14, 15, and 16 are formed by cutting a ceramic material having a thin plate shape. Meanwhile, the second plate 12 on which the ink reservoir 12a is formed, may be formed through injection molding or press-working a thin plastic material or an adhesive having a film shape, or through screen-printing an adhesive having a paste shape. The piezoelectric layer 21 formed on the sixth plate 16 is made by coating a ceramic material having a paste shape with a piezoelectric property and sintering the ceramic material.

[0010] As described above, in order to manufacture the conventional piezoelectric ink-jet printhead shown in FIG. 2, a plurality of metal plates and ceramic plates are separately processed using various processing methods, and then are stacked on one another and adhered to one another using a predetermined adhesive. However, in the conventional printhead, the number of plates constituting the printhead is quite large, and thus

the number of processes of aligning the plates is increased, thereby an alignment error is increased. If an alignment error occurs, ink is not smoothly supplied through the ink passage, thereby ink ejection performance of the printhead is lowered. In particular, as high-density printheads have been manufactured in order to improve printing resolution, improvement of precision in the above-mentioned alignment process is needed, thereby manufacturing costs are increased.

[0011] Also, the plurality of plates constituting the printhead are manufactured of different materials using different methods. Thus, a printhead manufacturing process becomes complicated, and it is difficult to adhere different materials to one another, thereby production yield is lowered. Also, even though the plurality of plates are precisely aligned and adhered to one another in the printhead manufacturing process, due to a difference in thermal expansion coefficients between different materials, caused by a variation in ambient temperature when the printhead is used, an alignment error or deformation may occur.

[0012] The present invention provides a piezoelectric ink-jet printhead, in which elements are integrated on three monocrystalline silicon substrates using a micromachining technology in order to realize a precise alignment, improve the adhering characteristics, and simplify a printhead manufacturing process, and a method for manufacturing the same.

[0013] According to an aspect of the present invention, there is provided a piezoelectric ink-jet printhead. The piezoelectric ink-jet printhead includes an upper substrate through which an ink supply hole, through which ink is supplied, is formed and a pressure chamber filled with ink to be ejected is formed on the bottom of the upper substrate, an intermediate substrate on which an ink reservoir which is connected to the ink supply hole and in which supplied ink is stored, is formed on the top of the intermediate substrate, and a damper is formed in a position which corresponds to one end of the pressure chamber, a lower substrate in which a nozzle, through which ink is to be ejected, is formed in a position which corresponds to the damper, and a piezoelectric actuator formed monolithically on the upper substrate and which provides a driving force for ejecting ink to the pressure chamber. A restrictor which connects the other end of the pressure chamber to the ink reservoir, is formed on at least one side of the bottom surface of the upper substrate and the top surface of the intermediate substrate, and the lower substrate, the intermediate substrate, and the upper substrate are sequentially stacked on one another and are adhered to one another, the three substrates being formed of a monocrystalline silicon substrate.

[0014] In an embodiment of the present invention, a portion forming an upper wall of the pressure chamber of the upper substrate serves as a vibration plate that is deformed by driving the piezoelectric actuator.

[0015] Here, it is preferable that the upper substrate is formed of a silicon-on-insulator (SOI) wafer having a structure in which a first silicon substrate, an intermediate oxide layer, and a second silicon substrate are sequentially stacked on one another, and the pressure chamber is formed on the first silicon substrate, and the second silicon substrate serves as the vibration plate.

[0016] It is also preferable that the pressure chamber is arranged in two columns at both sides of the ink reservoir, and in this case, in order to divide the ink reservoir in a vertical direction, a barrier wall is formed in the reservoir in a lengthwise direction of the ink reservoir.

[0017] Also, a silicon oxide layer is formed between the upper substrate and the piezoelectric actuator. Here, the silicon oxide layer suppresses material diffusion and thermal stress between the upper substrate and the piezoelectric actuator.

[0018] It is also preferable that the piezoelectric actuator includes a lower electrode formed on the upper substrate, a piezoelectric layer formed on the lower electrode to be placed on an upper portion of the pressure chamber, and an upper electrode, which is formed on the piezoelectric layer and which applies a voltage to the piezoelectric layer.

[0019] Here, the lower electrode has a two-layer structure in which a Ti layer and a Pt layer are stacked on each other, and the Ti layer and the Pt layer serve as a common electrode of the piezoelectric actuator and further serve as a diffusion barrier layer which prevents inter-diffusion between the upper substrate and the piezoelectric layer.

[0020] It is also preferable that the nozzle includes an orifice formed at a lower portion of the lower substrate, and an ink induction part which is formed at an upper portion of the lower substrate and connects the damper to the orifice.

[0021] Here, it is also preferable that the sectional area of the ink induction part is gradually reduced to the orifice from the damper, and the ink induction part is formed in a quadrangular pyramidal shape.

[0022] Also, the restrictor may have a rectangular section.

[0023] Meanwhile, the restrictor has a T-shaped section and is formed deeply in a vertical direction from the top surface of the intermediate substrate.

[0024] According to another aspect of the present invention, there is provided a method for manufacturing a piezoelectric ink-jet printhead. The method comprises preparing an upper substrate, an intermediate substrate, and a lower substrate, which are formed of a monocrystalline silicon substrate, micromachining the upper substrate, the intermediate substrate, and the lower substrate, respectively, to form an ink passage, stacking the lower substrate, the intermediate substrate, and the upper substrate, in each of which the ink passage has been formed, to adhere the lower substrate, the intermediate substrate, and the upper substrate to one another, and forming a piezoelectric actuator, which provides a driving force for ink ejection on the upper sub-

strate.

[0025] The method further comprises, before the forming of the ink passage, forming a base mark on each of the three substrates to align the three substrates during adhering the three substrate, and before the forming of the piezoelectric actuator, forming a silicon oxide layer on the upper substrate.

[0026] Preferably, the forming of the ink passage comprises forming a pressure chamber filled with ink to be ejected and an ink supply hole through which ink is supplied on the bottom of the upper substrate, forming a restrictor connected to one end of the pressure chamber, at least on one side of the bottom surface of the upper substrate, and the top surface of the intermediate substrate, forming a damper, connected to the other end of the pressure chamber, in the intermediate substrate, forming an ink reservoir, one end of which is connected to the ink supply hole and a side of which is connected to the restrictor, on the top of the intermediate substrate, and forming a nozzle, connected to the damper, in the lower substrate.

[0027] Preferably, in the forming of the pressure chamber and the ink supply hole, a silicon-on-insulator (SOI) wafer having a structure in which a first silicon substrate, an intermediate oxide layer, and a second silicon substrate are sequentially stacked on one another, is used for the upper substrate, and the first silicon substrate is etched using the intermediate oxide layer as an etch stop layer, thereby forming the pressure chamber and the ink supply hole.

[0028] In the forming of the restrictor, the bottom surface of the upper substrate or the top surface of the intermediate substrate are dry or wet etched. Meanwhile, the restrictor may be formed by forming part of the restrictor on the bottom of the upper substrate and forming the other part of the restrictor on the top of the intermediate substrate.

[0029] Also, in the forming of the restrictor, the top surface of the intermediate substrate is formed to a predetermined depth through dry etching using inductively coupled plasma (ICP), thereby forming the restrictor having a T-shaped section.

[0030] In this case, the forming of the restrictor and the forming of the ink reservoir are simultaneously performed.

[0031] Preferably, the forming of the damper comprises forming a hole having a predetermined depth connected to the other end of the pressure chamber, on the top of the intermediate substrate, and perforating the hole, thereby forming the damper connected to the other end of the pressure chamber.

[0032] Here, the forming of the hole is performed through sand blasting or dry etching using inductively coupled plasma (ICP), and the perforating the hole is performed through dry etching using ICP. Preferably, the perforating the hole is performed simultaneously with the forming of the ink reservoir.

[0033] Preferably, in the forming of the ink reservoir, the top surface of the intermediate substrate is dry etched to a predetermined depth, thereby forming the ink reservoir.

[0034] Preferably, the forming of the nozzle comprises etching the top surface of the lower substrate to a predetermined depth to form an ink induction part connected to the damper, and etching the bottom surface of the lower substrate to form an orifice connected to the ink induction part.

[0035] Preferably, in the forming of the ink induction part, the lower substrate is anisotropically wet etched using a silicon substrate having a crystalline face in a direction (100) as the lower substrate, thereby forming the ink induction part having a quadrangular pyramidal shape.

[0036] Preferably, in adhering, the stacking of the three substrates is performed using a mask aligner, and the adhering of the three substrates is performed using a silicon direct bonding (SDB) method. Preferably, in the adhering, in order to improve an adhering property of the three substrates, the three substrates are adhered to one another in a state where silicon oxide layers are formed at least on a bottom surface of the upper substrate and on a top surface of the lower substrate.

[0037] Preferably, the forming of the piezoelectric actuator comprises sequentially stacking a Ti layer and a Pt layer on the upper substrate to form a lower electrode, forming a piezoelectric layer on the lower electrode, and forming an upper electrode on the piezoelectric layer. The forming of the piezoelectric layer further comprises, after forming the upper electrode, dicing the adhered three substrates in units of a chip, and applying an electric field to the piezoelectric layer of the piezoelectric actuator to generate piezoelectric characteristics.

[0038] In the forming of the piezoelectric layer, a piezoelectric material in a paste state is coated on the lower electrode in a position which corresponds to the pressure chamber and is then sintered, thereby forming the piezoelectric layer, and the coating of the piezoelectric material is performed through screen-printing. Preferably, while the piezoelectric material is sintered, an oxide layer is formed on an inner wall of the ink passage formed on the three substrates. The sintering may be performed before the dicing or after the dicing.

[0039] According to another aspect of the present invention, there is provided a piezoelectric ink-jet printhead. The piezoelectric ink-jet printhead includes an ink reservoir in which ink is stored supplied from an ink container, a pressure chamber filled with ink to be ejected, a restrictor which connects the ink reservoir to the pressure chamber, a nozzle through which ink is ejected from the pressure chamber, and a piezoelectric actuator which provides a driving force for ejecting ink to the pressure chamber. The restrictor has a T-shaped section and is formed to be long in a vertical direction.

[0040] According to the above-mentioned present invention, elements constituting an ink passage, such as an ink reservoir and the pressure chamber, are formed

on three silicon substrates using a silicon micromachining technology, thereby the elements can be precisely and easily formed to a fine size on each of the three substrates. In addition, since the three substrates are formed of silicon, an adhering property to one another is high. Further, the number of substrates is reduced compared with the prior art, thereby a manufacturing process is simplified, and an alignment error is reduced.

[0041] The above and other aspects and advantages of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a cross-sectional view illustrating the typical structure of a conventional piezoelectric ink-jet printhead;
FIG. 2 is an exploded perspective view illustrating a conventional piezoelectric ink-jet printhead;
FIG. 3 is a cross-sectional view of the conventional piezoelectric ink-jet printhead in a lengthwise direction of a pressure chamber of FIG. 2;
FIG. 4 is a cross-sectional view taken along line A-A' of FIG. 3;
FIG. 5 is a sectional exploded perspective view illustrating an embodiment of a piezoelectric ink-jet printhead according to the present invention;
FIG. 6A is a cross-sectional view illustrating the embodiment of the piezoelectric ink-jet printhead in a lengthwise direction of a pressure chamber of FIG. 5;
FIG. 6B is an enlarged cross-sectional view taken along line B-B' of FIG. 6A;
FIG. 7 is an exploded perspective view illustrating another embodiment of the piezoelectric ink-jet printhead having a T-shaped restrictor according to the present invention;
FIGS. 8A through 8E are cross-sectional views illustrating the step of forming a base mark on an upper substrate in a method for manufacturing the piezoelectric ink-jet printhead according to the present invention;
FIGS. 9A through 9G are cross-sectional views illustrating the step of forming the pressure chamber on the upper substrate;
FIGS. 10A through 10E are cross-sectional views illustrating the step of forming a restrictor on an intermediate substrate;
FIGS. 11A through 11J are cross-sectional views illustrating a first method for forming an ink reservoir and a damper on the intermediate substrate in a stepwise manner;
FIGS. 12A and 12B are cross-sectional views illustrating a second method for forming the ink reservoir and the damper on the intermediate substrate in a stepwise manner;
FIGS. 13A through 13H are cross-sectional views illustrating the step of forming a nozzle on a lower substrate;
FIG. 14 is a cross-sectional view illustrating a step of sequentially stacking the lower substrate, the intermediate substrate, and the upper substrate, and adhering them to one another; and
FIGS. 15A and 15B are cross-sectional views illustrating a step of completing the piezoelectric ink-jet printhead according to an embodiment of the present invention by forming a piezoelectric actuator on the upper substrate.

[0042] Hereinafter, the present invention will be described in detail by describing preferred embodiments of the invention with reference to the accompanying drawings. This invention may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Like reference numerals denote elements having the same functions, and the size and thickness of an element may be exaggerated for clarity of explanation. It will be understood that when a layer is referred to as being on another layer or on a substrate, it can be directly on the other layer or on the substrate, or intervening layers may also be present.

[0043] FIG. 5 is a sectional exploded perspective view illustrating an embodiment of a piezoelectric ink-jet printhead according to the present invention, FIG. 6A is a cross-sectional view illustrating the embodiment of the piezoelectric ink-jet printhead in a lengthwise direction of a pressure chamber of FIG. 5, and FIG. 6B is an enlarged cross-sectional view taken along line B-B' of FIG. 6A.

[0044] Referring to FIGS. 5, 6A, and 6B, stacking three substrates 100, 200, and 300 on one another and adhering them to one another form a piezoelectric ink-jet printhead according to the above embodiment of the present invention. Elements constituting an ink passage are formed on each of the three substrates 100, 200, and 300, and a piezoelectric actuator 190 for generating a driving force for ink ejection is provided on the upper substrate 100. In particular, the three substrates 100, 200, and 300 are formed of a monocrystalline silicon wafer. As such, the elements constituting an ink passage can be precisely and easily formed to a fine size on each of the three substrates 100, 200, and 300, using a micromachining technology, such as photolithography or etching.

[0045] The ink passage includes an ink supply hole 110 through which ink is supplied from an ink container (not shown), an ink reservoir 210 in which ink flowed through the ink supply hole 110 is stored, a restrictor 220 for supplying ink to a pressure chamber 120 from the ink reservoir 210, the pressure chamber 120 which is to be filled with ink to be ejected, for generating a variation in pressure for ink ejection, and a nozzle 310 through which ink is ejected. Also, a damper 230 that concentrates an energy generated in the pressure chamber 120 by the piezoelectric actuator 190 and alleviates a rapid variation in pressure, may be formed be-

tween the pressure chamber 120 and the nozzle 310. As described above, the elements constituting the ink passage are allocated to each of the three substrates 100, 200, and 300 and are arranged on each of the three substrates 100, 200, and 300.

[0046] The pressure chamber 120 having a predetermined depth is formed on the bottom of the upper substrate 100, and the ink supply hole 110, a through hole, is formed at one side of the upper substrate 100. The pressure chamber 120 is formed in the shape of a longer cuboid in a flow direction of ink and is arranged in two columns at both sides of the ink reservoir 210 formed on the intermediate substrate 200. However, the pressure chamber 120 may be arranged only in one column at one side of the ink reservoir 210.

[0047] The upper substrate 100 is formed of a monocrystalline silicon wafer used in manufacturing integrated circuits (ICs), in particular, is preferably formed of a silicon-on-insulator (SOI) wafer. In general, the SOI wafer has a structure in which a first silicon substrate 101, an intermediate oxide layer 102 formed on the first silicon substrate 101, and a second silicon substrate 103 adhered onto the intermediate oxide layer 102 are sequentially stacked. The first silicon substrate 101 is formed of monocrystalline silicon and has a thickness of about several ten to several hundred µm. Oxidizing the surface of the first silicon substrate 101 may form the intermediate oxide layer 102, and the thickness of the intermediate oxide layer 102 is about several hundred Å to 2 µm. The second silicon substrate 103 is also formed of monocrystalline silicon, and its thickness is about several µm to several tens of µm. The reason the SOI wafer is used for the upper substrate 100 is that the height of the pressure chamber 120 can be precisely adjusted. That is, since the intermediate oxide layer 102 forming an intermediate layer of the SOI wafer serves as an etch stop layer, if the thickness of the first silicon substrate 101 is determined, the height of the pressure chamber 102 is determined accordingly. The second silicon substrate 103 forming an upper wall of the pressure chamber 120, is deformed by the piezoelectric actuator 190, thereby serves as a vibration plate for varying the volume of the pressure chamber 120. The thickness of the vibration plate is also determined by the thickness of the second silicon substrate 103. This will be described in detail later.

[0048] The piezoelectric actuator 190 is formed monolithically on the upper substrate 100. A silicon oxide layer 180 is formed between the upper substrate 100 and the piezoelectric actuator 190. The silicon oxide layer 180 serves as an insulating layer, suppresses material diffusion between the upper substrate 100 and the piezoelectric actuator 190, and adjusts a thermal stress. The piezoelectric actuator 190 includes lower electrodes 191 and 192, which serve as a common electrode; a piezoelectric layer 193 deformed by an applied voltage; and an upper electrode 194, which serves as a driving electrode. The lower electrodes 191 and 192 are formed on the entire surface of the silicon oxide layer 180 and preferably, are formed of two metal thin layers, such as a Ti layer 191 and a Pt layer 192. The Ti layer 191 and the Pt layer 192 serve as a common electrode and further serve as a diffusion barrier layer which prevents inter-diffusion between the piezoelectric layer 193 formed thereon and the upper substrate 100 formed there under. The piezoelectric layer 193 is formed on the lower electrodes 191 and 192 and is placed on an upper portion of the pressure chamber 120. The piezoelectric layer 193 is deformed by an applied voltage and serves to deform the second silicon substrate 103, i.e., the vibration plate, of the upper substrate 100 forming the upper wall of the pressure chamber 120. The upper electrode 194 is formed on the piezoelectric layer 193 and serves as a driving electrode for applying a voltage to the piezoelectric layer 193.

[0049] The ink reservoir 210 connected to the ink supply hole 110 is formed to a predetermined depth and to be longer on the top of the intermediate substrate 200, and the restrictor 220 for connecting the ink reservoir 210 to one end of the pressure chamber 120 is formed to be shallower. The damper 230 is formed vertically in the intermediate substrate 200 in a position which corresponds to the other end of the pressure chamber 120. The section of the damper 230 may be formed in a circular shape or a polygonal shape. As described above, if the pressure chamber 120 is arranged in two columns at both sides of the ink reservoir 210, the ink reservoir 210 is divided into two portions by forming a barrier wall 215 in the ink reservoir 210 in a lengthwise direction of the ink reservoir 210. This is preferable to smoothly supply ink and to prevent cross talk between the pressure chambers 120 disposed at both sides of the ink reservoir 210. The restrictor 220 serves as a passage through which ink is supplied to the pressure chamber 120 from the ink reservoir 120 and further serves to prevent ink from backwardly flowing to the ink reservoir 120 from the pressure chamber 120 when ink is ejected. In order to prevent the backward flow of ink, the sectional area of the restrictor 220 is much smaller than the sectional areas of the pressure chamber 120, and the damper 230, and is within a range in which the amount of ink is properly supplied to the pressure chamber 120.

[0050] Meanwhile, the restrictor 220 has been shown and described as formed on the top of the intermediate substrate 200. However, the restrictor 220, although not shown, may be formed on the bottom of the upper substrate 100, or part of the restrictor 220 may be formed on the bottom of the upper substrate 100 and the other part thereof may be formed on the top of the intermediate substrate 200. In the latter case, by adhering the upper substrate 100 to the intermediate substrate 200 the restrictor 220 results in a complete size.

[0051] The nozzle 310 is formed in a position, which corresponds to the damper 230, on the lower substrate 300. The nozzle 310 is comprised of an orifice 312, which is formed at the lower portion of the lower sub-

strate 300 and through which ink is ejected, and an ink induction part 311 which is formed at the upper portion of the lower substrate 300, connects the damper 230 to the orifice 312, and pressurizes and induces ink toward the orifice 312 from the damper 230. The orifice 312 is formed in a vertical hole having a predetermined diameter, and the ink induction part 311 is formed in a quadrangular pyramidal shape in which the area of the ink induction part 311 is gradually reduced to the orifice 312 from the damper 230. Meanwhile, the ink induction part 311 may be formed in a conic shape. However, as will be described later, it is preferable that the ink induction part 311 having a quadrangular pyramidal shape is formed on the lower substrate 300 formed of a monocrystalline silicon wafer.

[0052] As described previously, the three substrates 100, 200, and 300 are stacked on one another and are adhered to one another, thereby the piezoelectric ink-jet printhead according to the present invention is formed. The ink passage in which the ink supply hole 110, the ink reservoir 210, the restrictor 220, the pressure chamber 120, the damper 230, and the nozzle 310 are connected in sequence, is formed in the three substrates 100, 200, and 300.

[0053] The operation of the piezoelectric ink-jet printhead according to the present invention having the above structure will be described below.

[0054] Ink supplied to the ink reservoir 210 through the ink supply hole 110 from the ink container (not shown) is supplied to the pressure chamber 120 through the restrictor 220. If the pressure chamber 120 is filled with ink and a voltage is applied to the piezoelectric layer 193 through the upper electrode 194 of the piezoelectric actuator 190, the piezoelectric layer 193 is deformed. As such, the second silicon substrate 103 of the upper substrate 100, which serves as a vibration plate, is downwardly bent. Due to the flexural deformation of the second silicon substrate 103, the volume of the pressure chamber 120 is reduced, and due to an increase in pressure in the pressure chamber 120, ink in the pressure chamber 120 is ejected through the nozzle 310 via the damper 230. In this case, increasing pressure in the pressure chamber 120 is concentrated toward the damper 230 having a sectional area wider than the sectional area of the restrictor 220. Like this, the most part of ink in the pressure chamber 120 is discharged to the damper 230, and it is prevented ink from backwardly flowing to the ink reservoir 210 through the restrictor 220. Ink, which arrives at the nozzle 230 through the damper 230, is pressured by the ink induction part 311, and then the ink is ejected through the orifice 312.

[0055] Subsequently, if the voltage applied to the piezoelectric layer 193 of the piezoelectric actuator 190 is cut off, the piezoelectric layer 193 is restored to its original state, thereby the second silicon substrate 103 which serves as a vibration plate, is restored to its original state, and the volume of the pressure chamber 120 is increased. Due to a decrease in pressure in the pressure chamber 120, ink stored in the ink reservoir 210 is flowed to the pressure chamber 120 through the restrictor 220, thereby the pressure chamber 120 is again filled with ink.

[0056] Meanwhile, FIG. 7 illustrates another embodiment of the piezoelectric ink-jet printhead having a T-shaped restrictor according to the present invention. Here, like reference numerals in FIG. 5 denote elements having the same functions.

[0057] As shown in FIG. 7, except for a restrictor 220', the present embodiment is the same as the embodiment of FIG. 5. Thus, descriptions of like elements will be omitted, and only differences will be described below.

[0058] Referring to FIG. 7, the restrictor 220' for supplying ink to the pressure chamber 120 from the ink reservoir 210 has a T-shaped section and is formed deeply in a vertical direction from the top surface of the intermediate substrate 200. The depth of the restrictor 220' may be the same as or smaller than the depth of the ink reservoir 210. Likewise, the restrictor 220' has a very great depth compared with the restrictor 220 of FIG. 5, and thus, the entire volume is more increased than the volume of the restrictor 220 of FIG. 5. Thus, a variation in volume between the pressure chamber 120 and the restrictor 220' is reduced. According to the restrictor 220', flow resistance of ink supplied to the pressure chamber 120 from the ink reservoir 210 is reduced, and a pressure loss in step of supplying ink through the restrictor 220' is reduced. As such, quantity of flow passing the restrictor 220' is increased such that ink is more smoothly and quickly refilled in the pressure chamber 120. Consequently, even when the ink-jet printhead is driven in a high frequency region, uniform ink ejection volume and ink ejection speed can be obtained.

[0059] Meanwhile, as described above, the restrictor 220' having the T-shaped section may be also adopted in ink-jet printheads having different structures as well as in the piezoelectric ink-jet printhead having the structure of FIG. 7.

[0060] Hereinafter, a method for manufacturing the piezoelectric ink-jet printhead according to the present invention will be described with reference to the accompanying drawings. Hereinafter, the method will be described on the basis of the piezoelectric ink-jet printhead having the structure of FIG. 5. And, a method for manufacturing the piezoelectric ink-jet printhead having the structure of FIG. 7 according to the present invention will be described only in step of forming a restrictor.

[0061] To sum up, three substrates, such as an upper substrate, an intermediate substrate, and a lower substrate, in which elements for forming an ink passage are formed, are manufactured respectively, and then the three substrates are stacked on one another and are adhered to one another, and last, a piezoelectric actuator is formed on the upper substrate, thereby the piezoelectric ink-jet printhead according to the present invention is completed. Meanwhile, steps of manufacturing the upper, intermediate, and lower substrates may be

performed regardless of the substrates' order. That is, the lower substrate or intermediate substrate may be first manufactured, or two or all three substrates may be simultaneously manufactured. For convenience, the steps of manufacturing the upper substrate, the intermediate substrate, and the lower substrate will be sequentially described below. As described previously, the restrictor may be formed on the bottom of the upper substrate or on the top of the intermediate substrate, or part of the restrictor may be formed both on the bottom of the upper substrate and on the top of the lower substrate. However, to avoid complexity of descriptions thereof, the following shows that the restrictor is formed on the top of the intermediate substrate.

[0062] FIGS. 8A through 8E are cross-sectional views illustrating a step of forming a base mark on an upper substrate in a method for manufacturing the piezoelectric ink-jet printhead according to the present invention.

[0063] Referring to FIG. 8A, in the present embodiment, the upper substrate 100 is formed of a monocrystalline silicon substrate. This is because a silicon wafer that is widely used to manufacture semiconductor devices can be used without any changes, and thus is effective in mass production. The thickness of the upper substrate 100 is about 100 to 200 μm, preferably, about 130 to 150 μm and may be properly determined by the height of the pressure chamber (120 of FIG. 5) formed on the bottom of the upper substrate 100. It is preferable that the SOI wafer is used for the upper substrate 100, because the height of the pressure chamber (120 of FIG. 5) can be precisely formed. The SOI wafer, as described previously, has a structure in which the first silicon substrate 101, the intermediate oxide layer 102 formed on the first silicon substrate 101, and the second silicon substrate 103 adhered onto the intermediate oxide layer 102 are sequentially stacked. In particular, the second silicon substrate 103 has a thickness of several or several tens of μm in order to optimize the thickness of the vibration plate.

[0064] If the upper substrate 100 is put in an oxidation furnace and wet or dry oxidized, the top and bottom surfaces of the upper substrate 100 are oxidized, thereby silicon oxide layers 151a and 151b are formed.

[0065] Next, a photoresist (PR) is coated on the surface of the silicon oxide layers 151a and 151b, respectively, which are formed on the top and bottom of the upper substrate 100, as shown in FIG. 8B. Subsequently, the coated photoresist (PR) is developed, thereby an opening 141 for forming a base mark is formed in the vicinity of an edge of the upper substrate 100.

[0066] Next, a portion of the silicon oxide layers 151a and 151b exposed through the opening 141 is wet etched using the PR as an etch mask and removed, thereby the upper substrate 100 is partly exposed, and then the PR is stripped, as shown in FIG. 8C.

[0067] Next, the exposed portion of the upper substrate 100 is wet etched to a predetermined depth using the silicon oxide layers 151a and 151b as an etching mask, thereby a base mark 140 is formed, as shown in FIG. 8D. In this case, when the upper substrate 100 is wet etched, tetramethyl ammonium hydroxide (TMAH) or KOH, for example, may be used as a silicon etchant.

[0068] After the base mark 140 is formed, the remaining silicon oxide layers 151a and 151b are removed through wet etching. This is to clean foreign particles, such as by-products occurring when performing the above steps, simultaneously with removing the silicon oxide layers 151a and 151b.

[0069] As such, the upper substrate 100 in which the base mark 140 is formed in the vicinity of the edge of the top and bottom surfaces of the upper substrate 100, is prepared, as shown in FIG. 8E.

[0070] When the upper substrate 100, an intermediate substrate and a lower substrate, which will be described later, are stacked on one another and are adhered to one another, the base mark 140 is used to precisely align the upper substrate 100, the intermediate substrate, and the lower substrate. Thus, in case of the upper substrate 100, the base mark 140 may be formed only on the bottom of the upper substrate 100. In addition, when another alignment method or apparatus is used, the base mark 140 may be not needed, and in this case, the above steps are not performed.

[0071] FIGS. 9A through 9G are cross-sectional views illustrating a step of forming the pressure chamber on the upper substrate.

[0072] The upper substrate 100 is put in the oxidation furnace and is wet or dry oxidized, thereby silicon oxide layers 152a and 152b are formed on the top and bottom of the upper substrate 100, as shown in FIG. 9A. In this case, the silicon oxide layer 152b may be formed only on the bottom of the upper substrate 100.

[0073] Next, a photoresist (PR) is coated on the surface of the silicon oxide layer 152b formed on the bottom of the upper substrate 100, as shown in FIG. 9B. Subsequently, the coated photoresist (PR) is developed, thereby an opening 121 for forming a pressure chamber having a predetermined depth is formed on the bottom of the upper substrate 100.

[0074] Next, a portion of the silicon oxide layer 152b exposed through the opening 121 is removed through dry etching, such as reactive ion etching (RIE), using the photoresist (PR) as an etching mask, thereby the bottom surface of the upper substrate 100 is partly exposed, as shown in FIG. 9C. In this case, the silicon oxide layer 152b may also be removed through wet etching.

[0075] Next, the exposed portion of the upper substrate 100 is etched to a predetermined depth using the photoresist (PR) as an etching mask, thereby a pressure chamber 120 is formed, as shown in FIG. 9D. In this case, a dry etch process of the upper substrate 100 may be performed using inductively coupled plasma (ICP). As shown in FIG. 9D, if a SOI wafer is used for the upper substrate 100, an intermediate oxide layer 102 formed of a SOI wafer serves as an etch stop layer, and thus in

this step, only the first silicon substrate 101 is etched. Thus, if the thickness of the first silicon substrate 101, the pressure chamber 120 can be precisely adjusted to a desired height. The thickness of the first silicon substrate 101 may be easily adjusted during a wafer polishing process. Meanwhile, the second silicon substrate 103 for forming an upper wall of the pressure chamber 120 serves as a vibration plate, as described previously, and the thickness of the second silicon substrate 103 may be easily adjusted during the wafer polishing process.

[0076] After the pressure chamber 120 is formed, if the photoresist (PR) is stripped, the upper substrate 100 is prepared, as shown in FIG. 9E. However, in this state, foreign particles, such as by-products or polymer occurring in the above-mentioned wet etching, or RIE, or dry etch process using ICP, may be attached to the surface of the upper substrate 100. Thus, in order to remove these foreign particles, it is preferable that the entire surface of the upper substrate 100 is cleaned using sulfuric acid solution or TMAH. In this case, the remaining silicon oxide layers 152a and 152b are removed through wet etching, and part of the intermediate oxide layer 102 of the upper substrate 100, i.e., a portion forming the upper wall of the pressure chamber 120, is also removed.

[0077] As such, the upper substrate 100 in which the base mark 140 is formed in the vicinity of the edge of the top and bottom surfaces of the upper substrate 100 and the pressure chamber 120 is formed on the bottom of the upper substrate 100, is prepared, as shown in FIG. 9F.

[0078] As above, the upper substrate 100 is dry etched using the photoresist (PR) as the etching mask, thereby the pressure chamber 120 is formed, and the photoresist (PR) is stripped. However, on the contrary, the PR is stripped, and then the upper substrate 100 is dry etched using the silicon oxide layer 152b as the etching mask, thereby the pressure chamber 120 may be formed. That is, if the silicon oxide layer 152b formed on the bottom of the upper substrate 100 is comparatively thin, it is preferable that the photoresist (PR) is not stripped, and an etch process is performed to form the pressure chamber 120. If the silicon oxide layer 152b is comparatively thick, the photoresist (PR) is stripped, and then an etch process is performed to form the pressure chamber 120 using the silicon oxide layer 152b as the etching mask.

[0079] Silicon oxide layers 153a and 153b may be again formed on the top and bottom of the upper substrate 100 of FIG. 9F, as shown in FIG. 9G. In this case, the intermediate oxide layer 102 of which part is removed in the step shown in FIG. 9F, is compensated by the silicon oxide layer 153b. Likewise, if the silicon oxide layers 153a and 153b are formed, step of forming a silicon oxide layer 180 as an insulating layer on the upper substrate 100 may be omitted in the step of FIG. 15A, which will be described later. In addition, if the silicon oxide layer 153b is formed inside of the pressure chamber 120 for forming an ink passage, because of characteristics of the silicon oxide layer 153b, the silicon oxide layer 153b does not react with almost all kinds of ink, and thus a variety of ink can be used.

[0080] Meanwhile, although not shown, the ink supply hole (110 of FIG. 5) is also formed together with the pressure chamber 120 through the steps shown in FIGS. 9A through 9G. That is, in the step shown in FIG. 9G, the ink supply hole (110 of FIG. 5) having the same depth as a predetermined depth of the pressure chamber 120 is formed on the bottom of the upper substrate 100 together with the pressure chamber 120. The ink supply hole (110 of FIG. 5) formed to the predetermined depth on the bottom of the upper substrate 100, is penetrated using a sharp tool, such as a pin, after all manufacturing processes are completed.

[0081] FIGS. 10A through 10E are cross-sectional views illustrating a step of forming a restrictor on an intermediate substrate.

[0082] Referring to FIG. 10A, an intermediate substrate 200 is formed of a monocrystalline silicon substrate, and the thickness of the intermediate substrate 200 is about 200 to 300 μm. The thickness of the intermediate substrate 200 may be properly determined by the depth of the ink reservoir (210 of FIG. 5) formed on the intermediate substrate 200 and the length of the penetrated damper (230 of FIG. 5).

[0083] A base mark 240 is formed in the vicinity of an edge of the top and bottom surfaces of the intermediate substrate 200. Steps of forming the base mark 240 on the intermediate substrate 200 are the same as those shown in FIGS. 8A through 8E, and thus are not separately shown, and descriptions thereof will be omitted.

[0084] If the intermediate substrate 200, in which the base mark 240 is formed, is put in the oxidation furnace and is wet or dry etched, the top and bottom surfaces of the intermediate substrate 200 are oxidized, thereby silicon oxide layers 251a and 251b are formed, as shown in FIG. 10A.

[0085] Next, a photoresist (PR) is coated on the surface of the silicon oxide layer 251 a formed on the top of the intermediate substrate 200, as shown in FIG. 10B. Subsequently, the coated photoresist (PR) is developed, thereby an opening 221 for forming a restrictor is formed on the top of the intermediate substrate 200.

[0086] Next, a portion of the silicon oxide layer 251a exposed through the opening 221 is wet etched using the photoresist (PR) as an etch mask and removed, thereby the top surface of the intermediate substrate 200 is partly exposed, and then the photoresist (PR) is stripped, as shown in FIG. 10C. In this case, the silicon oxide layer 251a may be removed not through wet etching but through dry etching, such as RIE.

[0087] Next, the exposed portion of the intermediate substrate 200 is wet or dry etched to a predetermined depth using the silicon oxide layer 251a as an etching mask, thereby a restrictor 220 is formed, as shown in FIG. 10D. In this case, when the intermediate substrate

200 is wet etched, tetramethyl ammonium hydroxide (TMAH) or KOH, for example, may be used as a silicon etchant.

[0088] Subsequently, if the remaining silicon oxide layers 251a and 251b are removed through wet etching, the intermediate substrate 200 in which the restrictor 220 is formed in the vicinity of the edge of the top and bottom surfaces of the intermediate substrate 200, is prepared, as shown in FIG. 10E.

[0089] Meanwhile, the T-shaped restrictor shown in FIG. 7 is not formed in the above steps. That is, in this case, in the above steps, only the base mark 240 is formed on the intermediate substrate 200. And, the T-shaped restrictor may be formed together with an ink reservoir using the same method as a method for forming an ink reservoir in the following steps.

[0090] FIGS. 11A through 11J are cross-sectional views illustrating a first method for forming an ink reservoir and a damper on the intermediate substrate in a stepwise manner.

[0091] The intermediate substrate 200 is put in the oxidation furnace and is wet or dry oxidized, thereby silicon oxide layers 252a and 252b are formed on the top and bottom of the intermediate substrate 200, as shown in FIG. 11A. In this case, the silicon oxide layer 252a may be formed in a portion in which the restrictor 220 is formed.

[0092] Next, a photoresist (PR) is coated on the surface of the silicon oxide layer 252a formed on the top of the intermediate substrate 200, as shown in FIG. 11B. Subsequently, the coated photoresist (PR) is developed, thereby an opening 211 for forming an ink reservoir is formed on the top of the intermediate substrate 200. In this case, the photoresist (PR) remains in a portion in which a barrier wall is to be formed in the ink reservoir.

[0093] Next, a portion of the silicon oxide layer 252a exposed through the opening 211 is removed through wet etching using the photoresist (PR) as an etching mask, thereby the top surface of the intermediate substrate 200 is partly exposed, as shown in FIG. 11C. In this case, the silicon oxide layer 252a may also be removed not through wet etching but through dry etching, such as RIE.

[0094] Subsequently, after the photoresist (PR) is stripped, the intermediate substrate 200 is formed, as shown in FIG. 11D. Only a portion of the top surface of the intermediate substrate 200, in which the ink reservoir is to be formed, is exposed, and another portion of which is covered with the silicon oxide layers 252a and 252b.

[0095] Next, the photoresist (PR) is again coated on the surface of the silicon oxide layer 252a formed on the top of the intermediate substrate 200, as shown in FIG. 11E. In this case, the exposed portion of the top surface of the intermediate substrate 200 is also covered with the photoresist (PR). Subsequently, the coated photoresist (PR) is developed, thereby an opening 231 for forming a damper is formed on the top of the intermediate substrate 200.

[0096] Next, a portion of the silicon oxide layer 252a exposed through the opening 231 is removed through wet etching using the photoresist (PR) as an etching mask, thereby the top surface of the intermediate substrate 200 in which the damper is to be formed, is partly exposed, as shown in FIG. 11F. In this case, the silicon oxide layer 252a may also be removed not through wet etching but through dry etching, such as RIE.

[0097] Subsequently, the exposed portion of the intermediate substrate 200 is etched to a predetermined depth using the photoresist (PR) as the etching mask, thereby a damper forming hole 232 is formed. In this case, etching of the intermediate substrate 200 may be performed through dry etching using ICP.

[0098] Next, if the photoresist (PR) is stripped, the portion of the top surface of the intermediate substrate 200 in which the ink reservoir is to be formed is again exposed, as shown in FIG. 11H.

[0099] Subsequently, after the exposed portion of the top surface of the intermediate substrate 200 and the bottom surface of the damper forming hole 232 are dry etched using the silicon oxide layer 252a as the etching mask, a damper 230 through which the intermediate substrate 200 is passed, and the ink reservoir 210 having the predetermined depth are formed, as shown in FIG. 11I. In addition, a barrier wall 252, which divides the ink reservoir 210 in a vertical direction, is formed in the ink reservoir 210. In this case, etching of the intermediate substrate 200 may be performed through dry etching using ICP.

[0100] Next, the remaining silicon oxide layers 252a and 252b may be removed through wet etching. This is to clean foreign particles, such as by-products occurring when performing the above steps, simultaneously with removing the silicon oxide layers 252a and 252b.

[0101] As such, the intermediate substrate 200 in which the base mark 240, the restrictor 220, the ink reservoir 210, the barrier wall 215, and the damper 230 are formed, is prepared, as shown in FIG. 11J.

[0102] Meanwhile, although not shown, a silicon oxide layer may be again formed on the entire top and bottom surfaces of the intermediate substrate 200 of FIG. 11J.

[0103] FIGS. 12A and 12B are cross-sectional views illustrating a second method for forming the ink reservoir and the damper on the intermediate substrate in a stepwise manner. The second method, which will be described below, is similar to the first method, except for a step of forming a damper. Thus, hereinafter, only parts different from the above-mentioned first method will be described.

[0104] In the second method, steps of exposing only the portion in which the ink reservoir is to be formed, of the top surface of the intermediate substrate 200 are the same as those shown in FIGS. 11A through 11D.

[0105] Next, the photoresist (PR) is coated on the sur-

face of the silicon oxide layer 252a formed on the top of the intermediate substrate 200, as shown in FIG. 12A. In this case, the photoresist (PR) having a dry film shape is coated on the surface of the silicon oxide layer 252a using a lamination method including heating, pressurizing, and compressing processes. The dry film-shaped photoresist (PR) serves as a protecting layer for protecting another portion of the intermediate substrate 200 during a sand blasting process, which will be described later. Subsequently, the coated photoresist (PR) is developed, thereby the opening 231 for forming a damper is formed.

[0106] Subsequently, if the silicon oxide layer 252a exposed through the opening 231 and the intermediate substrate 200 up to a predetermined depth under the silicon oxide layer 252a are removed through sand blasting, a damper forming hole 232 having a predetermined depth is formed, as shown in FIG. 12B.

[0107] Next steps are the same as those shown in FIGS. 11H through 11J of the first method.

[0108] In this way, the second method is different from the first method in that the damper forming hole 232 is formed not through dry etching but sand blasting. That is, in order to form the damper forming hole 232, in the first method, the silicon oxide layer 252a is etched, and then the intermediate substrate 200 is dry etched to a predetermined depth, but in the second method, the silicon oxide layer 252a and the intermediate substrate 200 having the predetermined depth are removed through sand blasting at one time. Thus, the number of processes of the second method can be reduced compared to the number of processes of the first method, thereby also reducing the total processing time.

[0109] FIGS. 13A through 13H are cross-sectional views illustrating a step of forming a nozzle on a lower substrate.

[0110] Referring to FIG. 13A, a lower substrate 300 is formed of a monocrystalline silicon substrate, and the thickness of the lower substrate 300 is about 100 to 200 μm.

[0111] A base mark 340 is formed in the vicinity of an edge of the top and bottom surfaces of the lower substrate 300. Steps of forming the base mark 340 on the lower substrate 300 are the same as those shown in FIGS. 8A through 8E, and thus descriptions thereof will be omitted.

[0112] If the lower substrate 300, in which the base mark 340 is formed, is put in the oxidation furnace and is wet or dry etched, the top and bottom surfaces of the lower substrate 300 are oxidized, thereby silicon oxide layers 351a and 351b are formed, as shown in FIG. 13A.

[0113] Next, a photoresist (PR) is coated on the surface of the silicon oxide layer 351a formed on the top of the lower substrate 300, as shown in FIG. 13B. Subsequently, the coated photoresist (PR) is developed, thereby an opening 315 for forming an ink induction part of a nozzle is formed on the top of the lower substrate 200. The opening 315 is formed in a position which corresponds to the damper 230 formed on the intermediate substrate 200 shown in FIG. 11J.

[0114] Next, a portion of the silicon oxide layer 351a exposed through the opening 315 is wet etched using the photoresist (PR) as an etch mask and removed, thereby the top surface of the lower substrate 300 is partly exposed, and then the photoresist (PR) is stripped, as shown in FIG. 13C. In this case, the silicon oxide layer 351a may be removed not through wet etching but through dry etching, such as RIE.

[0115] Next, the exposed portion of the lower substrate 300 is wet etched to a predetermined depth using the silicon oxide layer 351a as an etching mask, thereby an ink induction part 311 is formed, as shown in FIG. 13D. In this case, when the lower substrate 300 is wet etched, for example, tetramethyl ammonium hydroxide (TMAH) or KOH may be used for an etchant. If a silicon substrate having a crystalline face in a direction (100) is used for the lower substrate 300, the ink induction part 311 having a quadrangular pyramidal shape can be formed using anisotropic wet etching characteristics of faces (100) and (111). That is, an etch rate of the face (111) is much smaller than the etch rate of the face (100), and thus the lower substrate 300 is etched inclined along the face (111) to form the ink induction part 311 having the quadrangular pyramidal shape. Accordingly, the bottom surface of the ink induction part 311 becomes the face (100).

[0116] Next, the photoresist (PR) is coated on the surface of the silicon oxide layer 351b formed on the bottom of the lower substrate 300, as shown in FIG. 13E. Subsequently, the coated photoresist (PR) is developed, thereby an opening 316 for forming an orifice of a nozzle is formed on the bottom of the lower substrate 300.

[0117] Next, a portion of the silicon oxide layer 351b exposed through the opening 316 is wet etched using the photoresist (PR) as an etch mask and is removed, thereby the bottom surface of the lower substrate 300 is partly exposed. In this case, the silicon oxide layer 351b may be removed not through wet etching but through dry etching, such as RIE.

[0118] Next, the exposed portion of the lower substrate 300 is etched using the PR as the etch mask so that the nozzle can be passed through the lower substrate 300, thereby an orifice 312 connected to the ink induction part 311 is formed. In this case, etching of the lower substrate 300 may be performed through dry etching using ICP.

[0119] Subsequently, after the photoresist (PR) is stripped, the lower substrate 300, in which a base mark 340 is formed in the vicinity of edges of the top and bottom surfaces of the lower surface 300 and through which a nozzle 310 comprised of the ink induction part 311 and the orifice 312 is passed, is prepared, as shown in FIG. 13H. Meanwhile, the orifice 312 is formed after the ink induction part 311 is formed as described above, but the ink induction part 311 may be formed after the orifice 312 is formed.

[0120] Also, the silicon oxide layers 351a and 351b formed on the top and bottom of the lower substrate 300 may be removed during a cleaning process, and subsequently, a new silicon oxide layer may be again formed on the entire surface of the lower substrate 300.

[0121] FIG. 14 is a cross-sectional view illustrating a step of sequentially stacking the lower substrate, the intermediate substrate, and the upper substrate and adhering them to one another.

[0122] Referring to FIG. 14, the lower substrate 300, the intermediate substrate 200, and the upper substrate 100, which are prepared through the above-mentioned steps, are sequentially stacked on one another and are adhered to one another. In this case, the intermediate substrate 200 is adhered to the lower substrate 300, and then the upper substrate is adhered to the intermediate substrate 200, but an adhesion order may be varied. The three substrates 100, 200, and 300 are aligned using a mask aligner, and alignment base marks 140, 240, and 340 are formed on each of the three substrates 100, 200, and 300, and thus an alignment precision is high. Adhesion to the three substrates 100, 200, and 300 may be performed through well-known silicon direct bonding (SDB). Meanwhile, in a SDB process, silicon adheres better to a silicon oxide layer than to another silicon layer. Thus, preferably, the upper substrate 100 and the lower substrate 300, on which the silicon oxide layers 153a, 153b, 351a, and 351b are formed, are used, and the intermediate substrate 200, on which a silicon oxide layer is not formed, is used, as shown in FIG. 14.

[0123] FIGS. 15A and 15B are cross-sectional views illustrating a step of completing the piezoelectric ink-jet printhead according to the present invention by forming a piezoelectric actuator on the upper substrate.

[0124] Referring to FIG. 15A, the lower substrate 100, the intermediate substrate 200, and the upper substrate 300 are stacked on one another in sequence and are adhered to one another, and a silicon oxide layer 180 is formed as an insulating layer on the top of the upper substrate 100. However, the step of forming the silicon oxide layer 180 may be omitted. That is, if the silicon oxide layer 153a has been already formed on the top of the upper substrate 100, as shown in FIG. 14, or if an oxide layer having a predetermined thickness has been already formed on the top of the upper substrate 100 in an annealing step of the above-mentioned SDB process, there is no need in forming the silicon oxide layer 180 shown in FIG. 15A as an insulating layer on the top of the upper substrate 100.

[0125] Subsequently, lower electrodes 191 and 192 of a piezoelectric actuator are formed on the silicon oxide layer 180. The lower electrodes 191 and 192 are formed of two metal thin layers, such as a Ti layer 191 and a Pt layer 192. The Ti layer 191 and the Pt layer 192 may be formed by sputtering the entire surface of the silicon oxide layer 180 to a predetermined thickness. The Ti layer 191 and the Pt layer 192 serve as a common electrode of the piezoelectric actuator and further serve as a diffusion barrier layer which prevents inter-diffusion between the piezoelectric layer (193 of FIG. 15b) formed thereon and the upper substrate 100 formed there under. In particular, the lower Ti layer 191 serves to improve an adhering property of the Pt layer 192.

[0126] Next, the piezoelectric layer 193 and the upper electrode 194 are formed on the lower electrodes 191 and 192, as shown in FIG. 15B. Specifically, a piezoelectric material in a paste state is coated on the pressure chamber 120 to a predetermined thickness through screen-printing, and then is dried for a predetermined amount of time. Preferably, typical lead zirconate titanate (PZT) ceramics are used for the piezoelectric layer 193. Subsequently, an electrode material, for example, Ag-Pd paste, is printed on the dried piezoelectric layer 193. Next, the piezoelectric layer 193 is sintered at a predetermined temperature, for example, at 900 to 1000°C. In this case, the Ti layer 191 and the Pt layer 192 prevent inter-diffusion between the piezoelectric layer 193 and the upper substrate 100 which may occur during a high temperature sintering process of the piezoelectric layer 193.

[0127] As such, a piezoelectric actuator 190 comprised of the lower electrodes 191 and 192, the piezoelectric layer 193, and the upper electrode 194 is formed on the upper substrate 100.

[0128] Meanwhile, sintering of the piezoelectric layer 193 is performed under atmospheric conditions, and thus in the sintering step, a silicon oxide layer is formed inside of the ink passage formed on the three substrates 100, 200, and 300. The silicon oxide layer does not react with almost all kinds of ink, and thus a variety of ink can be used. In addition, the silicon oxide layer has a hydrophilic property, and thus the in-flow of air bubbles is prevented when ink initially flows, and the occurrence of air bubbles is suppressed when ink is ejected through the nozzle.

[0129] Last, if a dicing process for cutting the adhered three substrates 100, 200, and 300 in units of a chip and a polling process of generating piezoelectric characteristics by applying an electric filed to the piezoelectric layer 193 are performed, the piezoelectric ink-jet printhead according to the present invention is completed. Meanwhile, the dicing process may be performed before the above-mentioned sintering step of the piezoelectric layer 193.

[0130] As described above, the piezoelectric ink-jet printhead and the method for manufacturing the same according to the present invention have the following advantages.

[0131] First, elements constituting the ink passage can be precisely and easily formed to a fine size on each of the three substrates formed of a monocrystalline silicon, using a silicon micromachining technology. Thus, a processing tolerance is reduced, thereby a deviation in ink ejecting performance can be minimized. In addition, the silicon substrate is used in the present invention, and thus can be also used in a process of manu-

facturing typical semiconductor devices, and mass production can be easily made. Thus, the present invention is suitable for high-density printheads in order to improve printing resolution.

[0132] Second, the three substrates are stacked on one another and are adhered to one another using the mask aligner, thereby a precise alignment and high productivity are obtained. That is, the number of adhered substrates is reduced compared with the prior art, thereby alignment and adhering processes are simplified, and an error in the alignment process is also reduced. In particular, if the base mark is formed on each substrate, precision in the alignment process is further improved.

[0133] Third, since the three substrates forming the printhead are formed of a monocrystalline silicon substrate, an adhering property thereto is high. Even through there is a variation in an ambient temperature when printing, since the thermal expansion coefficients of the substrates are equal to one another, a deformation or a subsequent alignment error does not occur.

[0134] Fourth, since the monocrystalline silicon substrate is used for a basic material, the surface roughness of an etch face is reduced after a dry or wet etch process, which benefits ink flow.

[0135] Fifth, since the silicon oxide layer, which does not react with almost all kinds of ink and has a hydrophilic property, is formed inside of the ink passage in several steps of the manufacturing process, a variety of inks can be used, and the in-flow of air bubbles is prevented when ink initially flows, and the occurrence of air bubbles is suppressed when ink is ejected through the nozzle.

[0136] Sixth, since part of the upper substrate formed of silicon with high mechanical characteristics serves as a vibration plate, the mechanical characteristics do not decrease even when the upper substrate is coupled to the piezoelectric actuator and then the piezoelectric actuator is driven for a long time.

[0137] Seventh, inter-diffusion between the piezoelectric layer and the upper substrate, in particular, between the piezoelectric layer and the vibration plate, which may occur during the sintering step of the piezoelectric layer, is prevented by the Ti and Pt layers, and the piezoelectric actuator and the vibration plate are adhered to each other without a gap therebetween, thereby deformation of the piezoelectric layer can be transferred to the vibration plate without temporal delay or displacement damages. Thus, since the vibration plate immediately vibrates by driving the piezoelectric actuator, ink ejection movement is performed rapidly. In addition, the present invention has the above-mentioned advantages even when the piezoelectric actuator is driven in a radio frequency region.

[0138] Eighth, when an ink-jet printhead has a T-shaped restrictor, flow resistance of ink supplied to the pressure chamber from the ink reservoir is reduced, and a pressure loss in step of supplying ink through the restrictor is reduced. As such, quantity of flow passing the restrictor is increased such that ink is more smoothly and quickly refilled in the pressure chamber. Thus, even when the ink-jet printhead is driven in a high frequency region, uniform ink ejection volume and ink ejection speed can be obtained.

[0139] Although preferred embodiments of the present invention have been described in detail, the scope of the present invention is not limited to these embodiments, and various changes thereto and other embodiments may be made. For example, forming elements of a piezoelectric ink-jet printhead according to the present invention, and a variety of etch methods may be applied in manufacturing an ink-jet printhead, and the order of each step of the method for manufacturing the piezoelectric ink-jet printhead may be varied.

[0140] While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

Claims

1. A piezoelectric ink-jet printhead comprising:

    an upper substrate through which an ink supply hole, through which ink is supplied, is formed and a pressure chamber filled with ink to be ejected is formed on the bottom of the upper substrate;
    an intermediate substrate on which an ink reservoir which is connected to the ink supply hole and in which supplied ink is stored, is formed on the top of the intermediate substrate, and a damper is formed in a position which corresponds to one end of the pressure chamber;
    a lower substrate in which a nozzle, through which ink is to be ejected, is formed in a position which corresponds to the damper; and
    a piezoelectric actuator formed monolithically on the upper substrate and which provides a driving force for ejecting ink to the pressure chamber;

    wherein a restrictor which connects the other end of the pressure chamber to the ink reservoir, is formed on at least one side of the bottom surface of the upper substrate and the top surface of the intermediate substrate, and the lower substrate, the intermediate substrate, and the upper substrate are sequentially stacked on one another and are adhered to one another, the three substrates being formed of a monocrystalline silicon substrate.

2. The printhead of claim 1, wherein a portion forming an upper wall of the pressure chamber of the upper substrate serves as a vibration plate that is deformed by driving the piezoelectric actuator.

3. The printhead of claim 2, wherein the upper substrate is formed of a silicon-on-insulator (SOI) wafer having a structure in which a first silicon substrate, an intermediate oxide layer, and a second silicon substrate are sequentially stacked on one another, and the pressure chamber is formed on the first silicon substrate, and the second silicon substrate serves as the vibration plate.

4. The printhead of any preceding claim, wherein the pressure chamber is arranged in two columns at both sides of the ink reservoir.

5. The printhead of claim 4, wherein in order to divide the ink reservoir in a vertical direction, a barrier wall is formed in the reservoir in a lengthwise direction of the ink reservoir.

6. The printhead of any preceding claim, wherein a silicon oxide layer is formed between the upper substrate and the piezoelectric actuator.

7. The printhead of claim 6, wherein the silicon oxide layer suppresses material diffusion and thermal stress between the upper substrate and the piezoelectric actuator.

8. The printhead of any preceding claim, wherein the piezoelectric actuator comprises:

   a lower electrode formed on the upper substrate;
   a piezoelectric layer formed on the lower electrode to be placed on an upper portion of the pressure chamber; and
   an upper electrode, which is formed on the piezoelectric layer and which applies a voltage to the piezoelectric layer.

9. The printhead of claim 8, wherein the lower electrode has a two-layer structure in which a Ti layer and a Pt layer are stacked on each other.

10. The printhead of claim 9, wherein the Ti layer and the Pt layer serve as a common electrode of the piezoelectric actuator and further serve as a diffusion barrier layer which prevents inter-diffusion between the upper substrate and the piezoelectric layer.

11. The printhead of any preceding claim, wherein the nozzle comprises:

   an orifice formed at a lower portion of the lower substrate; and
   an ink induction part which is formed at an upper portion of the lower substrate and connects the damper to the orifice.

12. The printhead of claim 11, wherein the sectional area of the ink induction part is gradually reduced to the orifice from the damper.

13. The printhead of claim 12, wherein the ink induction part is formed in a quadrangular pyramidal shape.

14. The printhead of any preceding claim, wherein the restrictor has a T-shaped section and is formed deeply in a vertical direction from the top surface of the intermediate substrate.

15. A method for manufacturing a piezoelectric ink-jet printhead, the method comprising:

   preparing an upper substrate, an intermediate substrate, and a lower substrate, which are formed of a monocrystalline silicon substrate;
   micromachining the upper substrate, the intermediate substrate, and the lower substrate, respectively, to form an ink passage;
   stacking the lower substrate, the intermediate substrate, and the upper substrate, in each of which the ink passage has been formed, to adhere the lower substrate, the intermediate substrate, and the upper substrate to one another; and
   forming a piezoelectric actuator, which provides a driving force for ink ejection on the upper substrate.

16. The method of claim 15 further comprising, before the forming of the ink passage, forming a base mark on each of the three substrates to align the three substrates during adhering the three substrate.

17. The method of claim 16, wherein in the forming of the base mark, the vicinity of at least an edge of the bottom surface of the upper substrate and the vicinity of edges of the top and bottom surfaces of the intermediate substrate and the lower substrate are etched to a predetermined thickness, thereby forming the base mark.

18. The method of claim 17, wherein the base mark is formed through wet etching using a tetramethyl ammonium hydroxide (TMAH) or KOH as an etchant.

19. The method of any of claims 15 to 18, wherein the forming of the ink passage comprises:

   forming a pressure chamber filled with ink to be ejected and an ink supply hole through which

ink is supplied on the bottom of the upper substrate;
forming a restrictor connected to one end of the pressure chamber, at least on one side of the bottom surface of the upper substrate, and the top surface of the intermediate substrate;
forming a damper, connected to the other end of the pressure chamber, in the intermediate substrate;
forming an ink reservoir, one end of which is connected to the ink supply hole and a side of which is connected to the restrictor, on the top of the intermediate substrate; and
forming a nozzle, connected to the damper, in the lower substrate.

20. The method of claim 19, wherein in the forming of the pressure chamber and the ink supply hole, the bottom surface of the upper substrate is dry etched to a predetermined depth, thereby simultaneously forming the pressure chamber and the ink supply hole.

21. The method of claim 20, wherein in the forming of the pressure chamber and the ink supply hole, a silicon-on-insulator (SOI) wafer having a structure in which a first silicon substrate, an intermediate oxide layer, and a second silicon substrate are sequentially stacked on one another, is used for the upper substrate, and the first silicon substrate is etched using the intermediate oxide layer as an etch stop layer, thereby forming the pressure chamber and the ink supply hole.

22. The method of claim 20, wherein after the forming of the pressure chamber and the ink supply hole, the entire surface of the upper substrate is cleaned using a tetramethyl ammonium hydroxide (TMAH).

23. The method of claim 20, wherein the ink supply hole formed to a predetermined depth on the bottom of the upper substrate is perforated after forming the piezoelectric actuator.

24. The method of any of claims 19 to 23, wherein in the forming of the restrictor, the bottom surface of the upper substrate is dry etched or wet etched using a TMAH or KOH as an etchant, thereby forming the restrictor.

25. The method of any of claims 19 to 23, wherein in the forming of the restrictor, the top surface of the intermediate substrate is dry etched or wet etched using a TMAH or KOH as an etchant, thereby forming the restrictor.

26. The method of any of claims 19 to 23, wherein in the forming of the restrictor, the bottom surface of the upper substrate and the top surface of the intermediate substrate are dry etched, respectively, or wet etched, respectively, using a TMAH or KOH as an etchant, thereby forming part of the restrictor on the bottom of the upper substrate and forming the other part of the restrictor on the top of the intermediate substrate.

27. The method of any of claims 19 to 23, wherein in the forming of the restrictor, the top surface of the intermediate substrate is etched to a predetermined depth through dry etching using inductively coupled plasma (ICP), thereby forming the restrictor having a T-shaped section.

28. The method of claim 27, wherein the forming of the restrictor and the forming of the ink reservoir are simultaneously performed.

29. The method of any of claims 19 to 28, wherein the forming of the damper comprises:

forming a hole having a predetermined depth connected to the other end of the pressure chamber, on the top of the intermediate substrate; and
perforating the hole, thereby forming the damper connected to the other end of the pressure chamber.

30. The method of claim 29, wherein the forming of the hole is performed through sand blasting, and the perforating the hole is performed through dry etching using ICP.

31. The method of claim 30, wherein before the sand blasting, a dry film-shaped photoresist is coated using a lamination method as a protecting layer for protecting another portion of the intermediate substrate on the intermediate substrate.

32. The method of claim 29, wherein the forming of the hole and the perforating the hole are performed through dry etching using ICP.

33. The method of claim 29, wherein the perforating the hole is performed simultaneously with the forming of the ink reservoir.

34. The method of any of claims 19 to 33, wherein the forming of the ink reservoir, the top surface of the intermediate substrate is dry etched to a predetermined depth, thereby forming the ink reservoir.

35. The method of claim 34, wherein the forming of the ink reservoir, in order to divide the ink reservoir in a vertical direction, a barrier wall is formed in the ink reservoir in a lengthwise direction of the ink reser-

voir.

36. The method of claim 34 or 35, wherein the ink reservoir is formed through dry etching using ICP.

37. The method of any of claims 19 to 36, wherein the forming of the nozzle comprises:

    etching the top surface of the lower substrate to a predetermined depth to form an ink induction part connected to the damper; and
    etching the bottom surface of the lower substrate to form an orifice connected to the ink induction part.

38. The method of claim 37, wherein in the forming of the ink induction part, the lower substrate is anisotropically wet etched using a silicon substrate having a crystalline face in a direction (100) as the lower substrate, thereby forming the ink induction part having a quadrangular pyramidal shape.

39. The method of any of claims 15 to 38, wherein in adhering, the stacking of the three substrates is performed using a mask aligner.

40. The method of any of claims 15 to 38, wherein in adhering, the adhering of the three substrates is performed using a silicon direct bonding (SDB) method.

41. The method of claim 40, wherein in the adhering, in order to improve an adhering property of the three substrates, the three substrates are adhered to one another in a state where silicon oxide layers are formed at least on a bottom surface of the upper substrate and on a top surface of the lower substrate.

42. The method of any of claims 15 to 41 further comprising, before the forming of the piezoelectric actuator, forming a silicon oxide layer on the upper substrate.

43. The method of any of claims 15 to 42, wherein the forming of the piezoelectric actuator comprises:

    sequentially stacking a Ti layer and a Pt layer on the upper substrate to form a lower electrode;
    forming a piezoelectric layer on the lower electrode; and
    forming an upper electrode on the piezoelectric layer.

44. The method of claim 43, wherein in the forming of the piezoelectric layer, a piezoelectric material in a paste state is coated on the lower electrode in a position which corresponds to the pressure chamber and is then sintered, thereby forming the piezoelectric layer.

45. The method of claim 44, wherein the coating of the piezoelectric material is performed through screen-printing.

46. The method of claim 44, wherein while the piezoelectric material is sintered, an oxide layer is formed on an inner wall of the ink passage formed on the three substrates.

47. The method of any of claims 43 to 46, wherein the forming of the piezoelectric actuator comprises:

    after forming the upper electrode, dicing the adhered three substrates in units of a chip; and
    applying an electric field to the piezoelectric layer of the piezoelectric actuator to generate piezoelectric characteristics.

48. A piezoelectric ink-jet printhead comprising:

    an ink reservoir in which ink is stored supplied from an ink container;
    a pressure chamber filled with ink to be ejected;
    a restrictor which connects the ink reservoir to the pressure chamber;
    a nozzle through which ink is ejected from the pressure chamber; and
    a piezoelectric actuator which provides a driving force for ejecting ink to the pressure chamber;

    wherein the restrictor has a T-shaped section and is formed to be long in a vertical direction.

FIG. 1 (PRIOR ART)

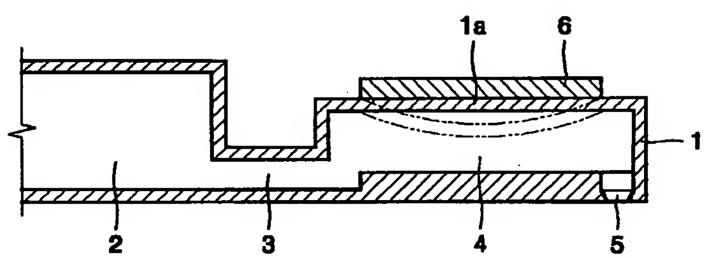

FIG. 2 (PRIOR ART)

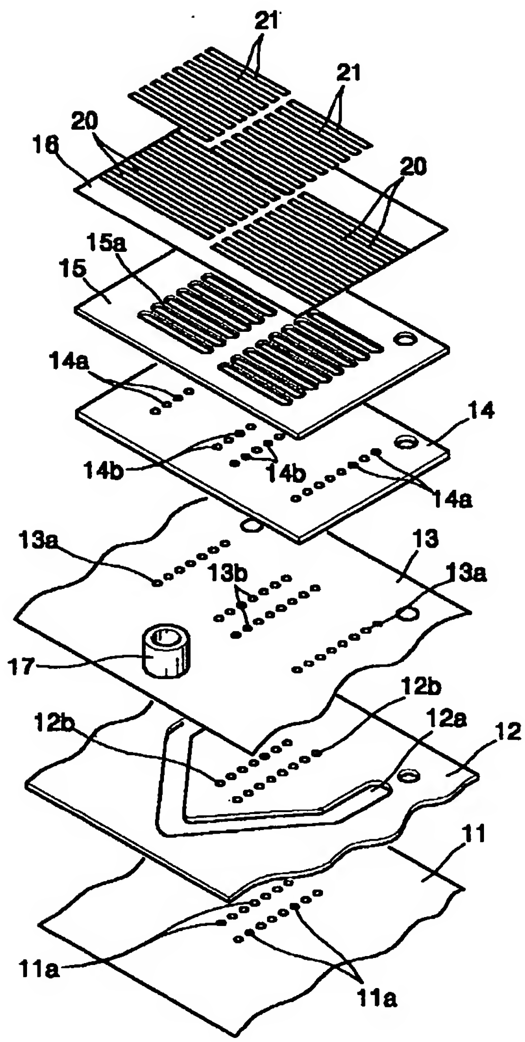

FIG. 3 (PRIOR ART)

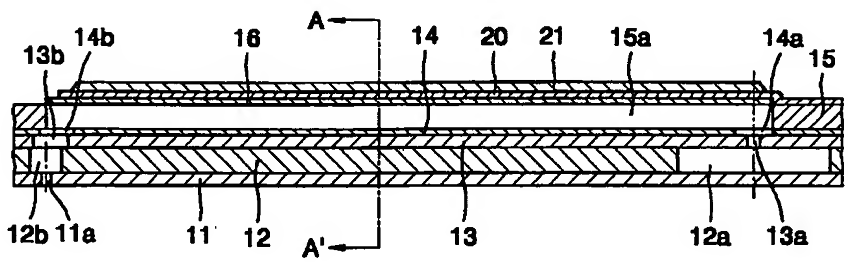

FIG. 4 (PRIOR ART)

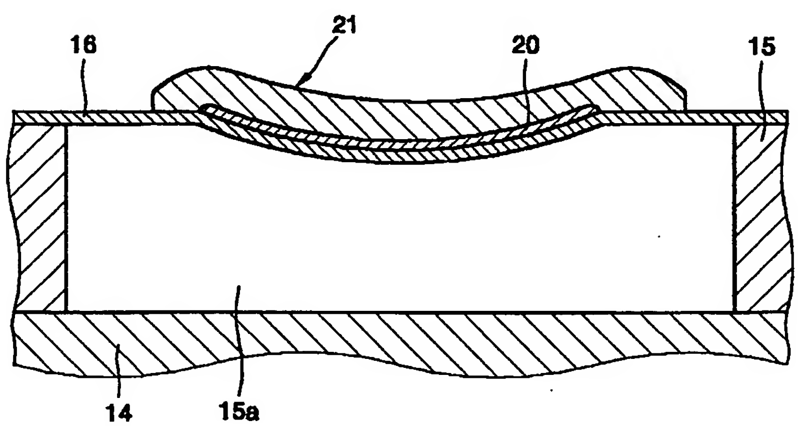

FIG. 5

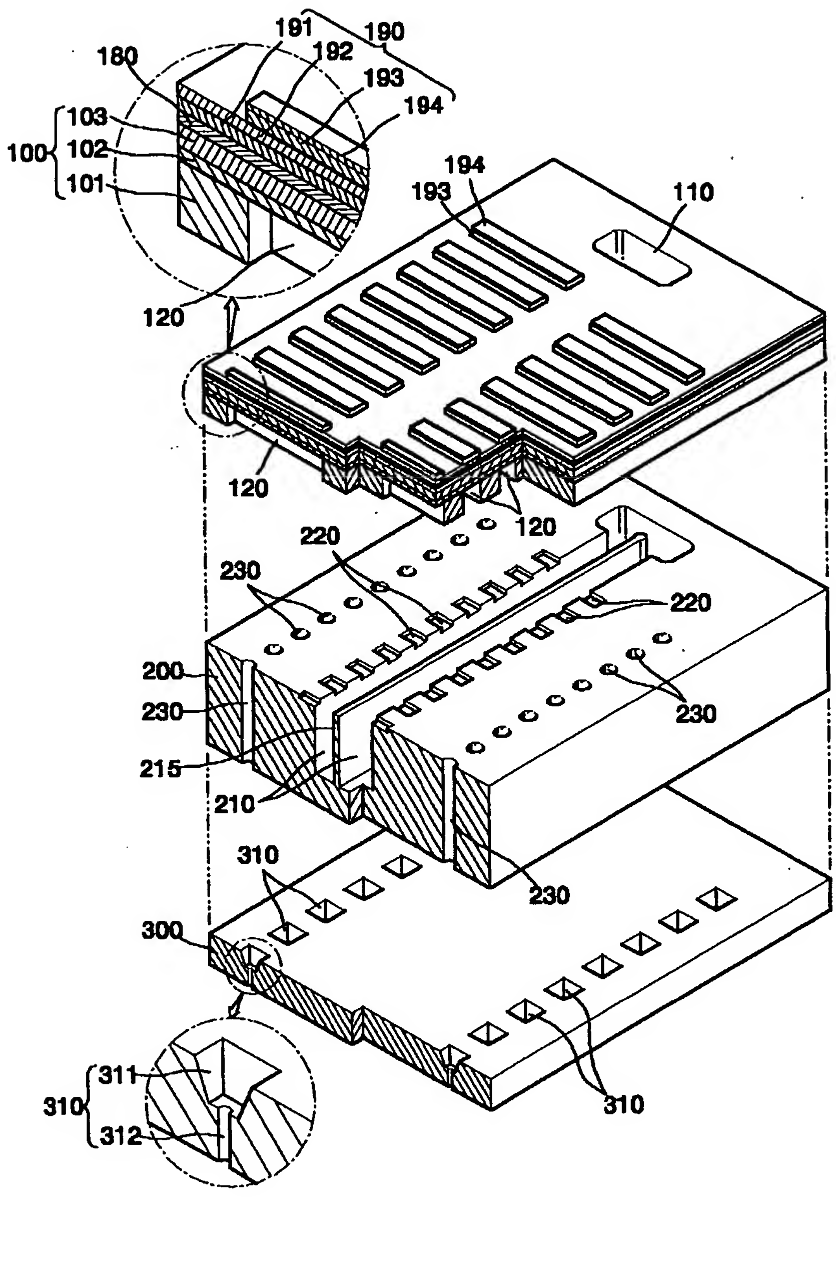
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FIG. 6A

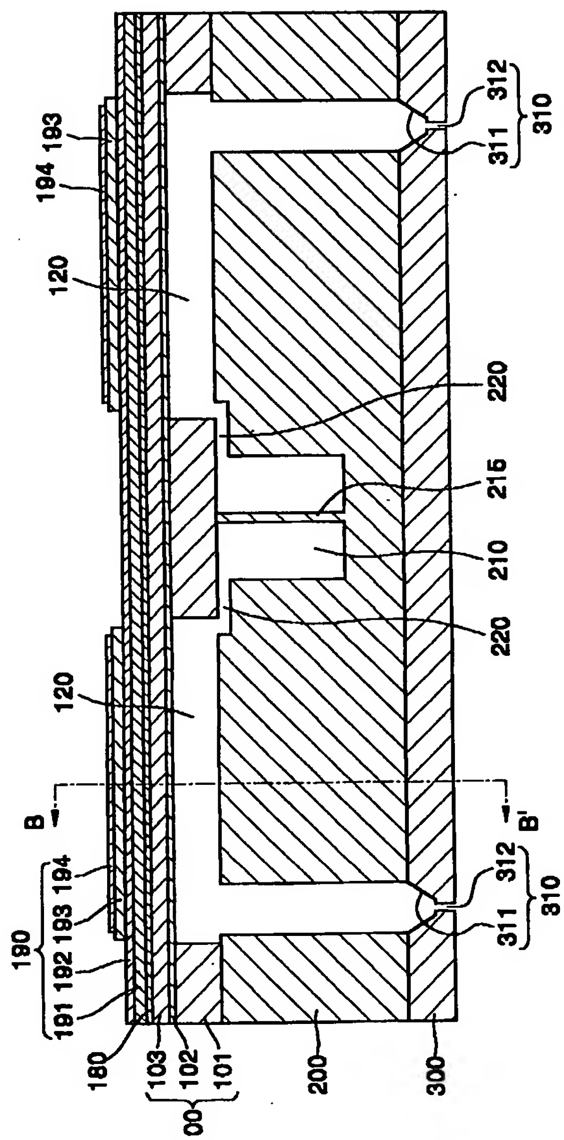
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FIG. 6B

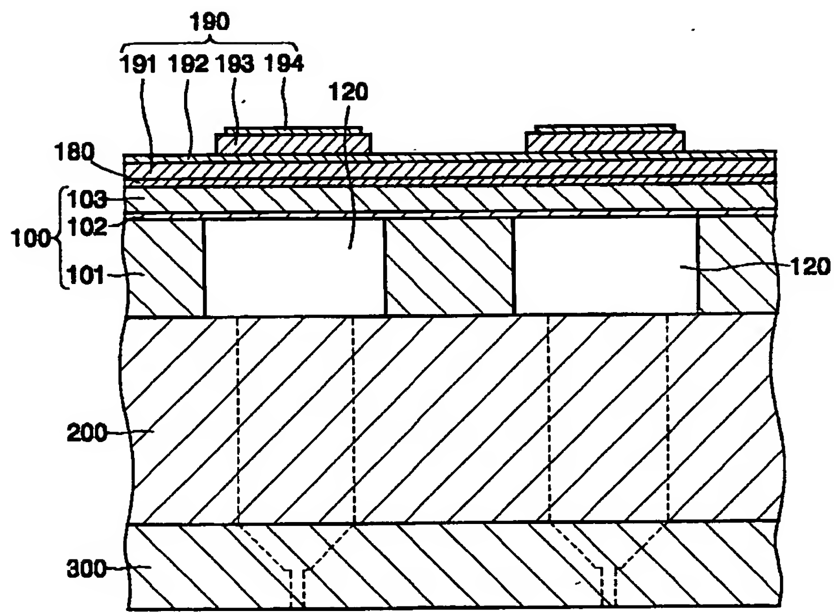

FIG. 7

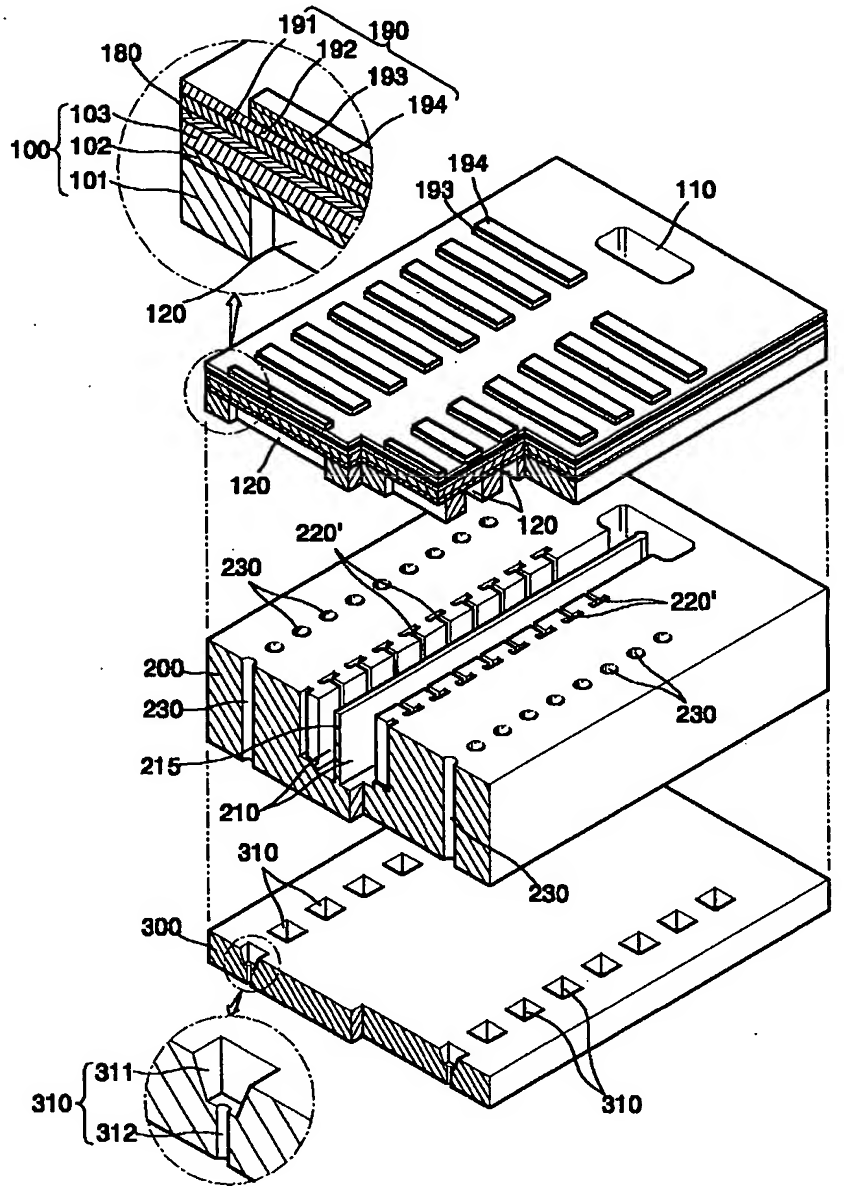
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FIG. 8A

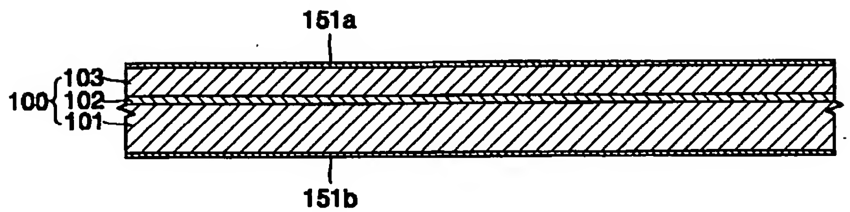

FIG. 8B

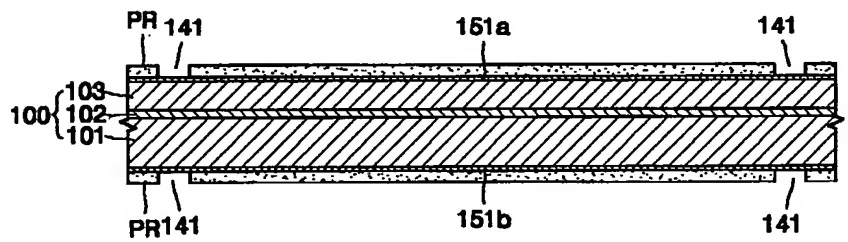

FIG. 8C

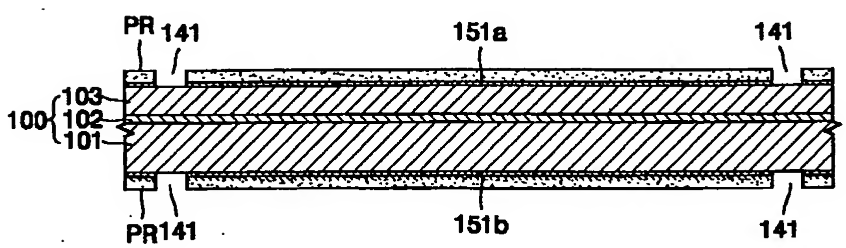

FIG. 8D

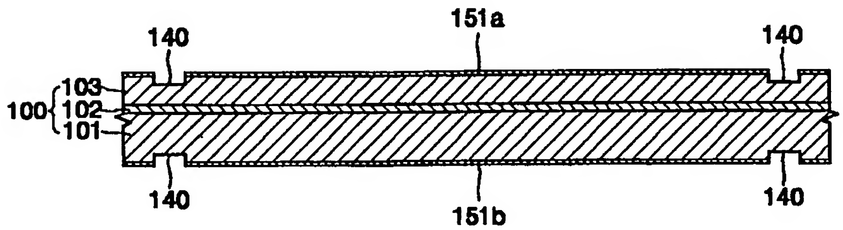

FIG. 8E

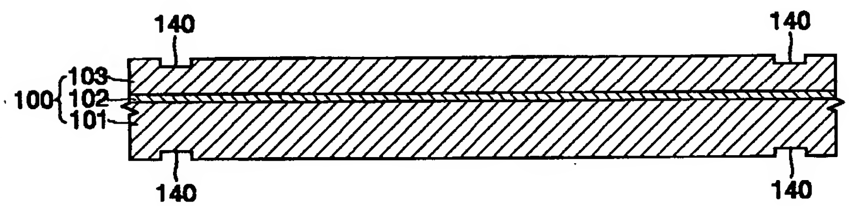

FIG. 9A

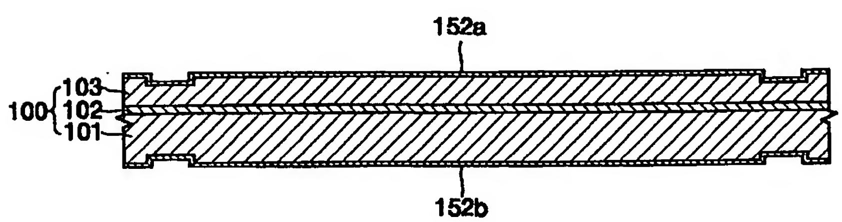

FIG. 9B

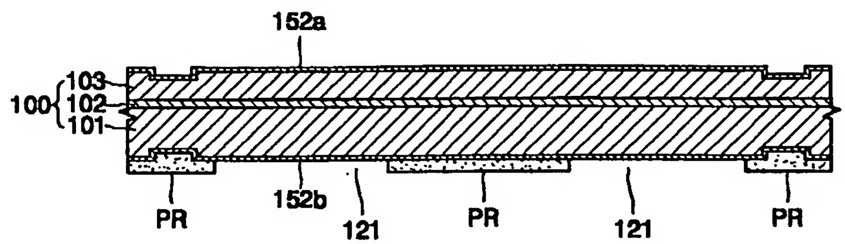

FIG. 9C

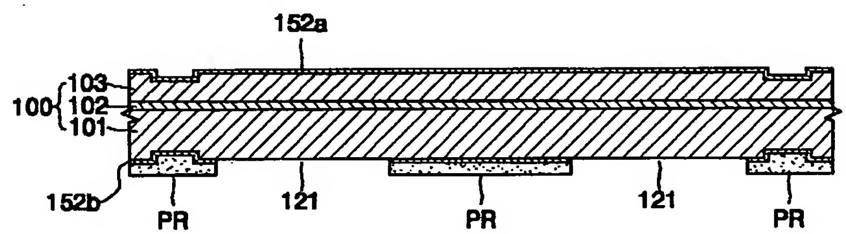

FIG. 9D

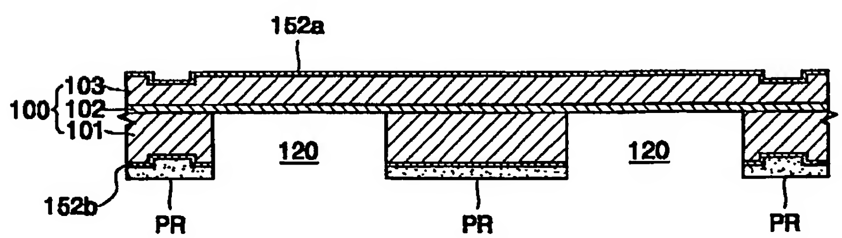

FIG. 9E

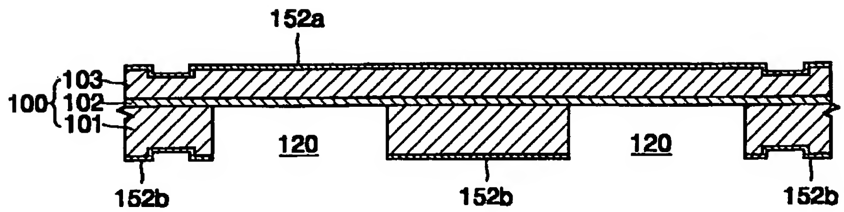

FIG. 9F

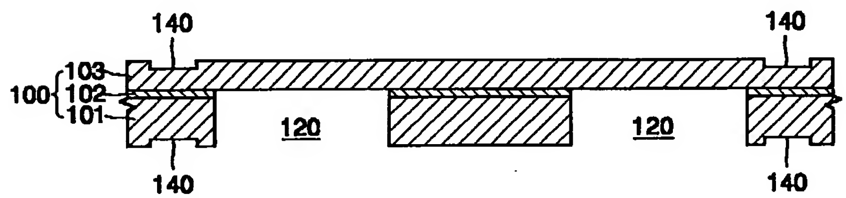

FIG. 9G

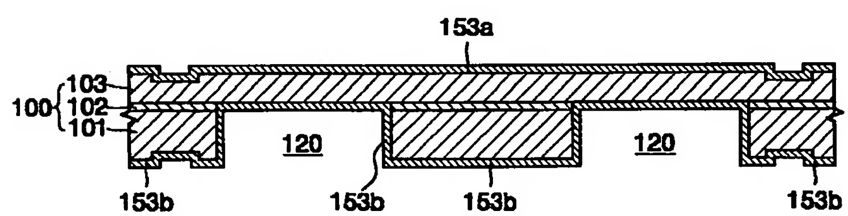

FIG. 10A

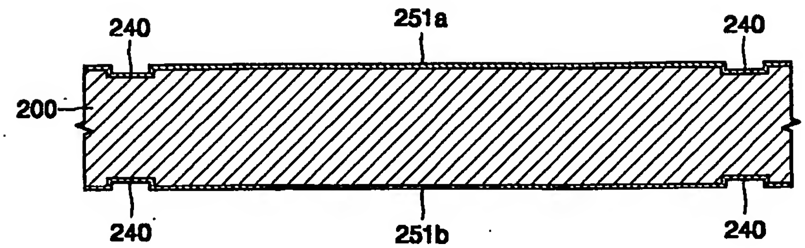

FIG. 10B

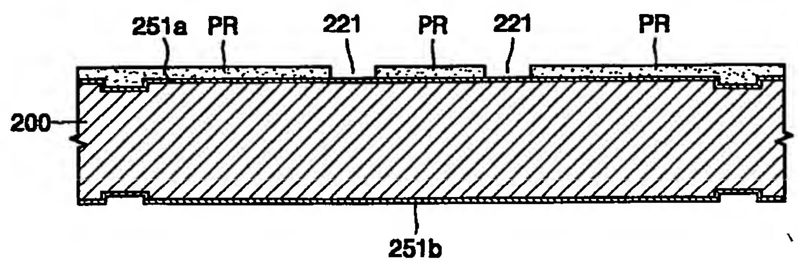

FIG. 10C

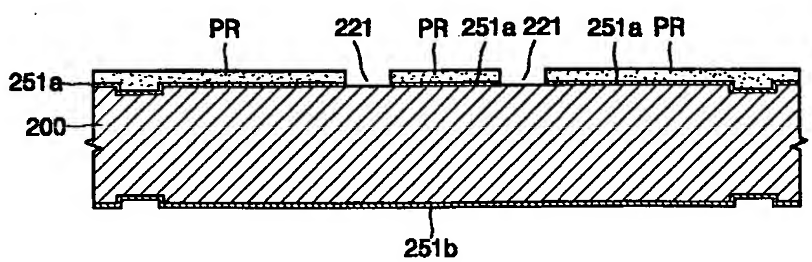

FIG. 10D

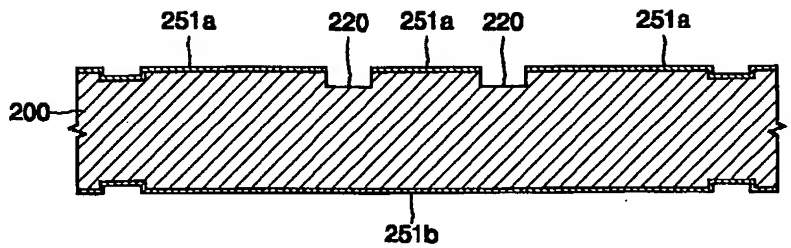

FIG. 10E

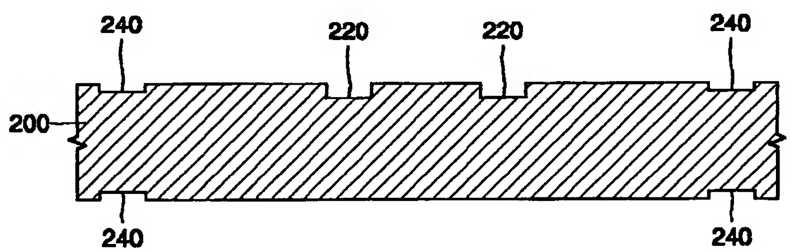

FIG. 11A

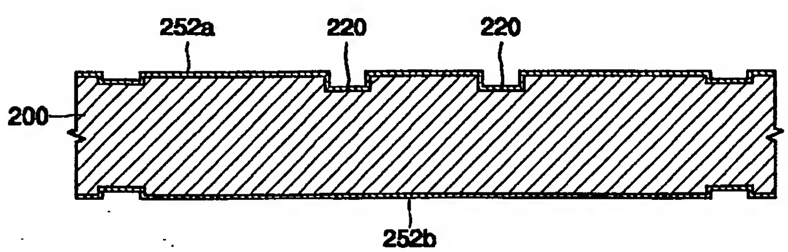

FIG. 11B

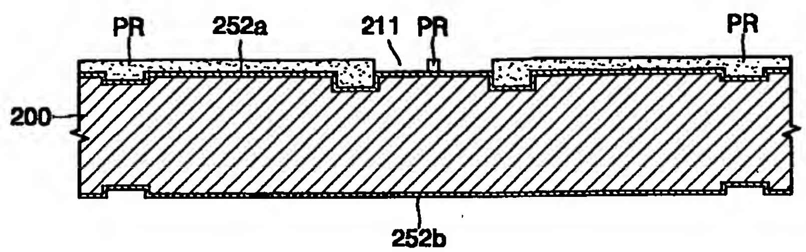

FIG. 11C

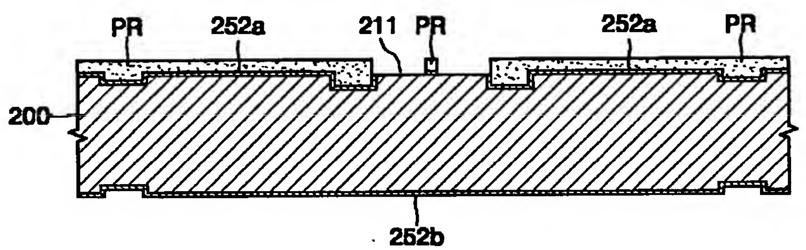

FIG. 11D

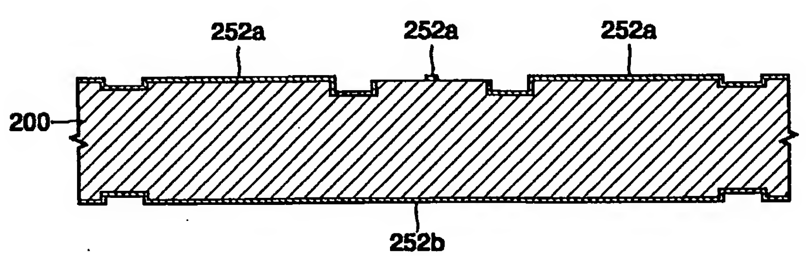

FIG. 11E

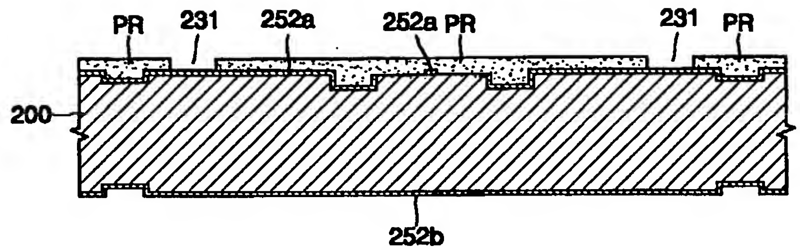

FIG. 11F

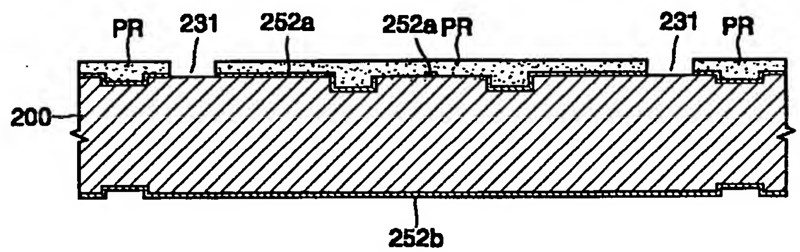

FIG. 11G

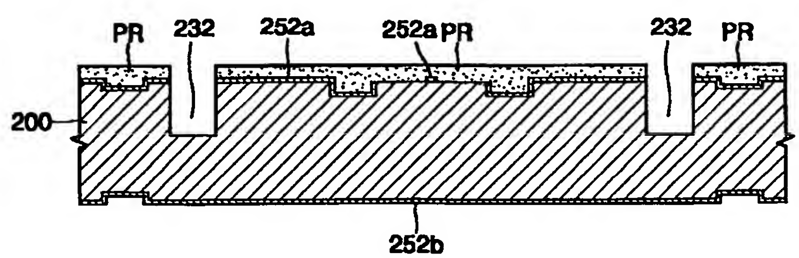

FIG. 11H

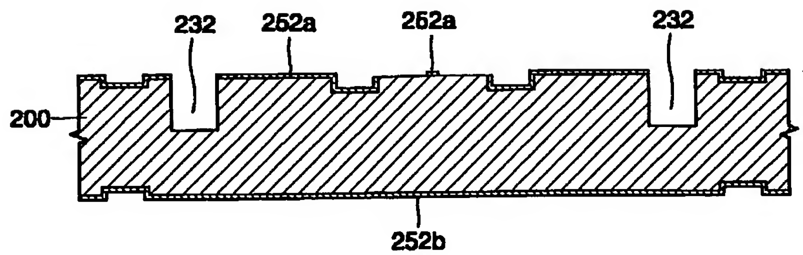

FIG. 11I

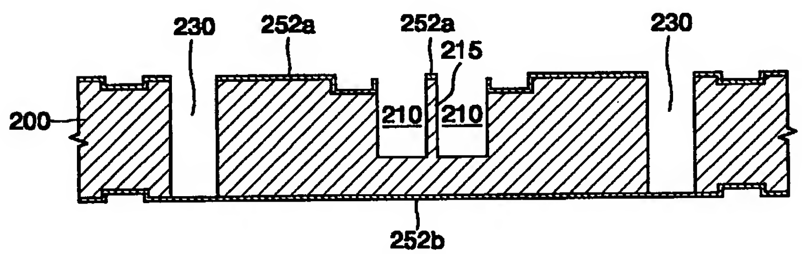

FIG. 11J

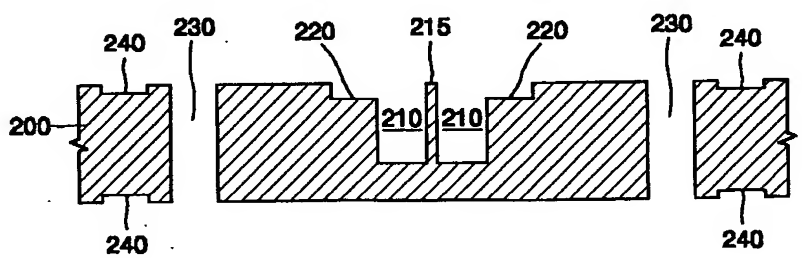

FIG. 12A

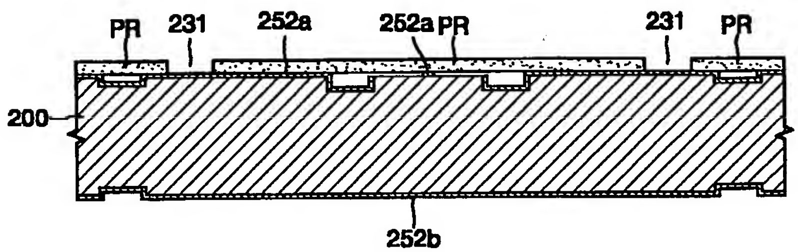

FIG. 12B

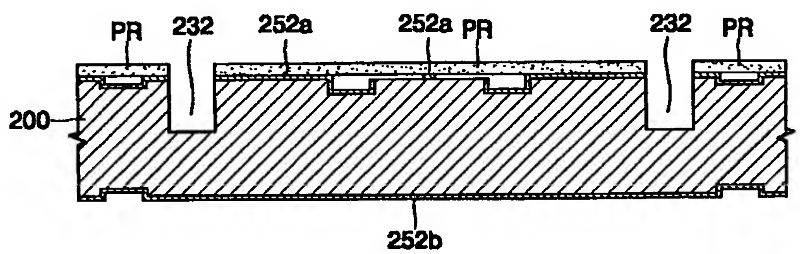

FIG. 13A

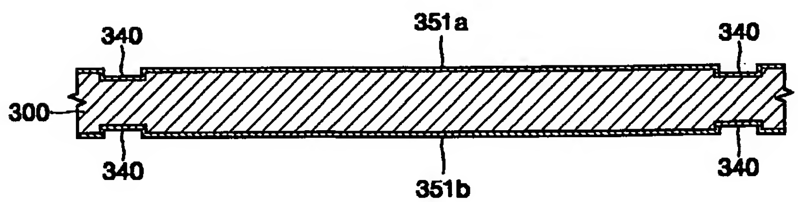

FIG. 13B

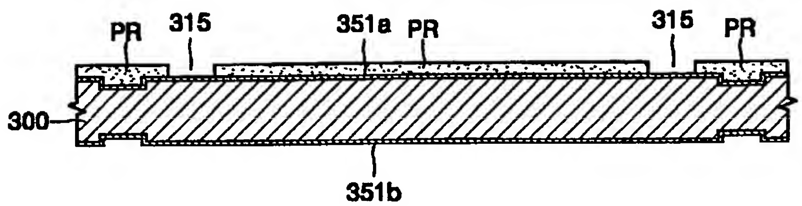

FIG. 13C

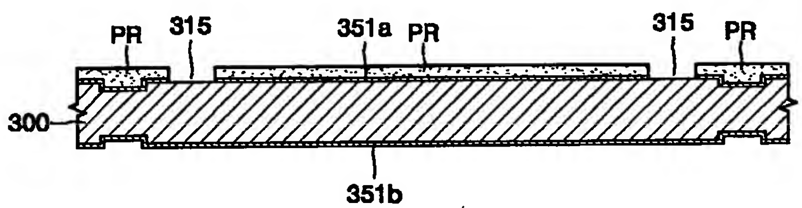

FIG. 13D

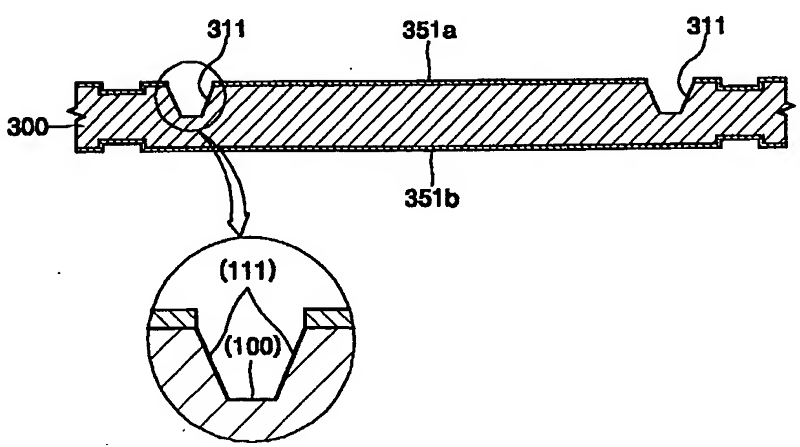

FIG. 13E

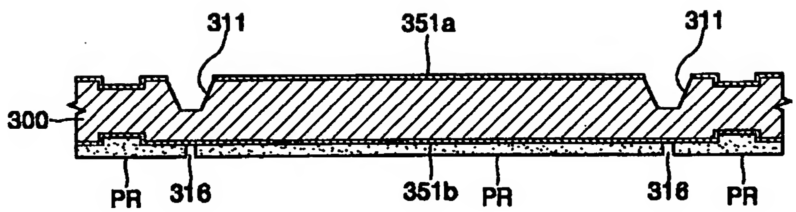

FIG. 13F

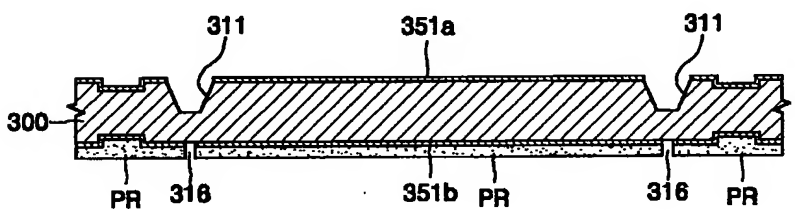

FIG. 13G

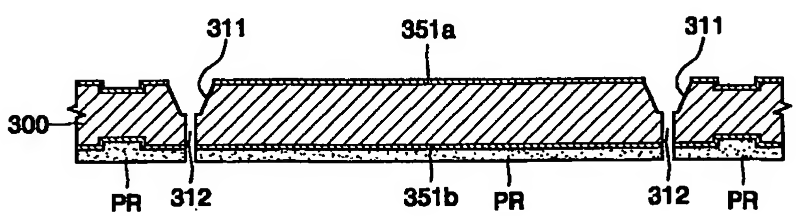

FIG. 13H

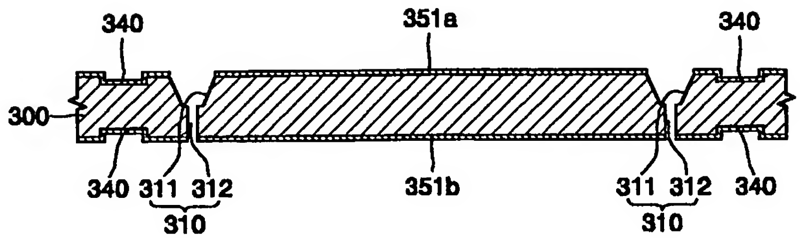

FIG. 14

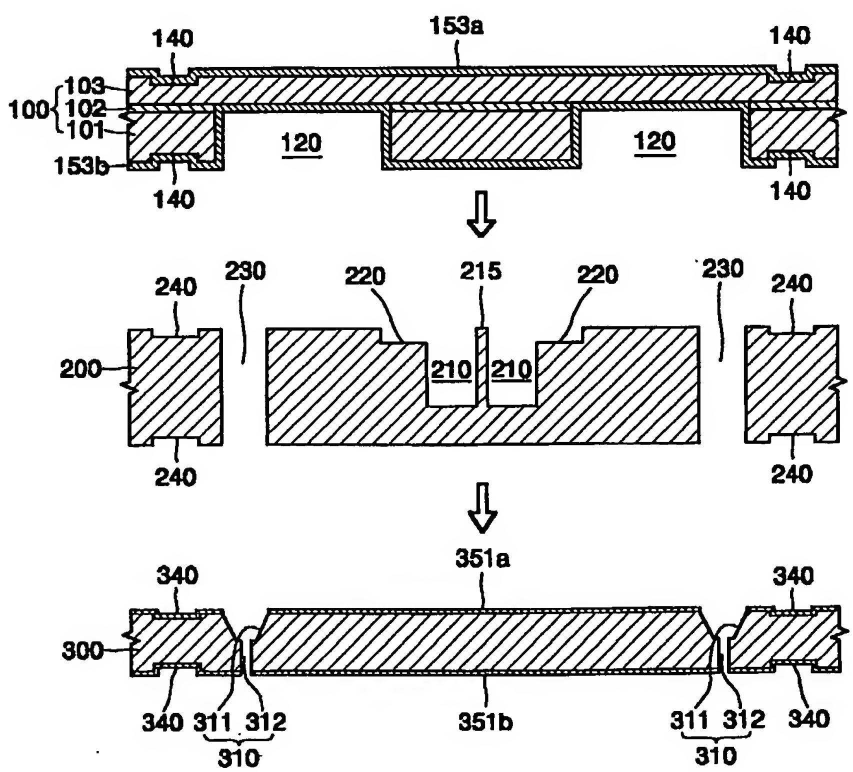

FIG. 15A

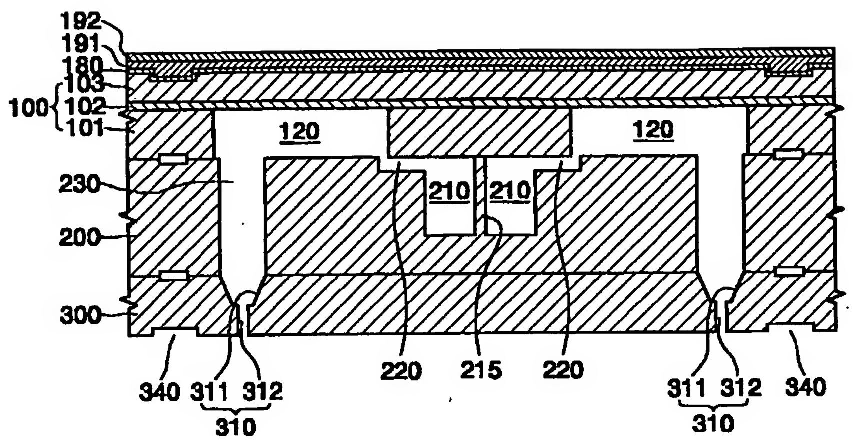

FIG. 15B